POINTS
FOR
Buyers & Users
OF
TOOL STEEL

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POINTS

FOR

BUYERS AND USERS OF

TOOL STEEL

By

GEORGE W. ALLING, M.E.

BEING A GENERAL REVIEW OF THE MAIN SOURCES
OF TROUBLE MET WITH BY CONSUMERS OF
TOOL STEEL, ALSO CONTAINING
SUGGESTIONS ABOUT HOW
TO AVOID THEM

(ILLUSTRATED)

DAVID WILLIAMS COMPANY
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DEDICATION.

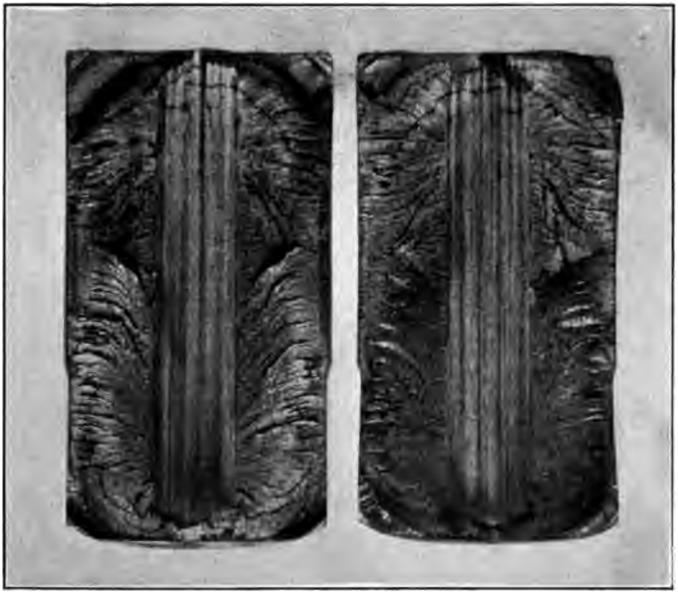
With a deep sense of appreciation of the courteous treatment received from the gentlemen named below, as well as from many other conscientious men, who, while fully safeguarding their firms' best interests, find time to accord courteous treatment to all, this work is respectfully dedicated to

H. O. HUKILL, Purchasing Agent for Pennsylvania Lines west of Pittsburgh, Pa., and

A. F. COLLING, Purchasing Agent for International Steam Pump Co., New York City, N. Y.

With the best regards of the author:

G. W. ALLING.



A Male Watch Case Die, burst in hardening because of piped center, one of the defects commonly found in carelessly inspected steel.

PREFACE.

PRIMARILY this work is designed for those who have not had the benefit of a technical education so as to enable them to extract from the numerous books that have been written on this subject the information which we have attempted to give in plainer language.

At the same time it is possible that the college graduate may find some points herein, which may be of use to him in actual shop practice, that may have been omitted in the existing books, under the impression that they were of minor importance.

No attempt has been made to contradict any of the many theories laid down by the numerous writers who have written on this subject, some of which doubtless have merit.

In short every effort has been made to employ plain language and simple descriptions, such as are best appreciated by practical mechanics, and such as can be readily applied by practical men in ordinary shops not equipped with all modern appliances, under the direction of a technically educated superintendent or master mechanic.

It is presumed that the average consumer of tool steel is most interested in obtaining results in the simplest and cheapest way, and that he will be glad to secure a work that will be easily understood by the workman on whom he depends to produce these results. To this end the very confusing remarks and tables about percentages of carbon for this and that sort of tool, which some are so fond of indulging in, and which are often very misleading and unreliable, have been omitted.

A little thought on the part of the reader will convince him that it is among the impossibilities to establish fixed rules for amounts of carbon for certain kinds of tools, when the fact is taken into consideration that this amount may be combined with

many different kinds of iron of varying quality, may be subjected to many kinds of treatment in making the steel, and to many more kinds of treatment in producing the tool at the hands of the various men who make them.

The views expressed about hardening, and the various methods used, may perhaps be slightly tinged with the writer's personal views, but these have been frequently confirmed by observation as well as by the testimony of first-rate mechanics. If they are found in some respects erroneous, it is hoped that they will be overlooked as only general rules are described.

Advertising in the reading matter of any sort has also been avoided, as what might justly be considered the best to-day may prove inferior in the near future.

It is an established fact that perfection can only be acquired by actual practice, and books simply assist a good mechanic as the lighthouse and compass assist the skillful pilot, and the chart tells where to find and avoid the rocks. The writer will feel well repaid if this small work should help the mechanic to steer clear of the numerous rocks and shoals found in the path of every toolmaker who has to make the many kinds of tools from the many kinds of steel furnished by the many kinds of steel makers.

It is hoped that the inexperienced buyer of steel and the average toolmaker will glean a few points from this work which will amply repay them for the trouble of reading it, and that they will find that it fills some of the gaps left open by abler writers.

The day is fast approaching when the high-class mechanic will supply himself with all printed information regarding his particular trade, and, after reading it, will separate the wheat from the chaff and apply what he finds good to actual practice.

If he finds by practical test that this work is worthy of a place amongst his reference books, the writer will be amply rewarded for the pains taken in writing it.

Yours very faithfully,

G. W. ALLING,

New York City.

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PART FIRST.

CHAPTER I.

STUMBLING BLOCKS ENCOUNTERED BY BUYERS WHO ARE NOT MECHANICS.

It may require some fine discrimination on the part of the purchasing agent who has graduated from college and taken up the duties of buying the supplies for a large manufacturing concern to know how to buy the most economical steel for various purposes for which tool steel is required in the diversified industries. He often finds that the technical education he has spent so much time and money in acquiring leaves him somewhat in the dark when he comes in contact with actual practice and with the variety of requirements of the different men for whom he has to buy. He finds that prejudice has grown strong from long experience with trash that has been given the workman as good tool steel until the latter has acquired the impression that only one certain steel is suitable for use in all kinds of tools, no matter what sort of tools they may be or who is going to use them. This man may be a bright and up to date mechanic in every other particular, a competent foreman, a first-class tool maker and an excellent blacksmith, or even a superintendent capable of handling several hundred men, and yet he may be thoroughly impregnated with this idea regarding the particular brand of steel that he happened to use when working on a lathe, a planer and the various other machines that all good mechanics have

to familiarize themselves with before they become competent to fill the position of superintendent to the best advantage of their employer.

The buyer will find that he often has to yield to these conflicting ideas in order to keep peace in the shop. He will also find when he attempts to introduce into the shop a new steel which is recommended to him as superior to what he is using that the men who are intrusted with the testing of it start in to make the test with a partial judgment already formed, which is usually prejudicial to the new steel. The prejudice is partly an outgrowth of the idea that the buyer is trying to give him something that is cheaper in price in order to save a few cents on each pound of steel. Instead of giving the steel a fair test at the same speed, on the same kind of work with the same cut, he proceeds to select an extra hard piece of material which the regular steel would not cut, and probably no other would. When he has not got such material handy he will increase the speed of his machine to a point beyond what could be expected of any steel, and he also increases the amount of his feed or depth of cut. Of course, the tool gives way, and he returns it to the superintendent, or to the office, with the nose rubbed off, or broken, with the report that it is no better than the old steel, or not as good, or something more to its disadvantage. He then goes back to his work with the idea that he has settled that steel for good. The tool is laid one side to await the arrival of the salesman who sold the steel, and when he comes he is shown the result of the test that he asked for. If he knows his business he sees at once that he has been the victim of shop prejudice, and proceeds to convince the buyer of this fact, which is made easier if the steel has been highly recommended to

the buyer by some disinterested party who may be using it. Often the salesman is rash enough to say that he can go into the shop and prove that the steel is all that he claimed for it, and more. The buyer will often have him do so, which is the wrong course for both buyer and salesman, nine times out of ten. Of course, there may be cases where this is the only alternative where the adverse report has been made by the head mechanic, with the information that he, himself, supervised the test. When this occurs the salesman must put on his softest gloves and handle the case with the discretion of a diplomat, or he will offend the man whom it is his desire to convince, and make an active enemy instead of a desirable customer for his firm.

In the other nine cases it is much better for the buyer to call the superintendent, master mechanic or foreman into his office to meet the salesman, and let the salesman question him in regard to how the test was made and who made it. The superintendent, who is generally a busy man, will probably say: " I gave the tool to Sam Brown and told him to test it and report to me, and he did so." Now, Sam Brown may be the right hand man of the superintendent, and one of his best mechanics, and the soft gloves must be used here to avoid offending both the superintendent and Sam Brown.

In the most diplomatic manner the salesman must proceed to convince the superintendent that Mr. Brown probably misunderstood the nature of the steel and mistook it for one of those about which he had heard so many extravagant stories, and really ran it a speed beyond what could be expected of any steel, or on harder material than could be worked successfully by any steel of a similar nature.

If the superintendent is broad minded and has the interests of the firm at heart, he will go to Sam Brown and diplomatically convince him that he did not give the steel a fair show, and that he probably mistook it for a high speed steel, such as he might have heard about but never saw, for there are limits to high speed steels as well as others. The superintendent will also say that So-and So is using this steel and finds it much better than that we are using, and if others can do more with it he ought to be able to do so.

This puts Sam on his metal, and he proceeds to try it again under different conditions. He will put in one of his regular tools and run it until it is dull, timing it. Then he will put the test tool in at same speed and with same cut, time it, and find that it runs considerably longer than the other without losing its edge. He then gets interested, and proceeds to find out just how much the tool will stand. By figuring up the time of the two tools he finds that the new tool has run fully 30 per cent. longer than the other. He is well acquainted with the capabilities of the old steel, so lays the old tool on one side and starts an exhaustive test to satisfy himself as to how much can be done with this new steel so that he will make no second mistake. He then increases the feed 30 per cent. and times the tool again, and to his surprise finds that it runs nearly the same time as on the other feed. At this stage he becomes thoroughly convinced that he has made an ass of himself before, and admits to the superintendent that the steel is undoubtedly better than the old steel. To carry this conviction further and find the limit of endurance, he then increases the speed of his machine 25 per cent., and to his surprise the tool stands almost as long as it did on the first trail, at the

lower speed and less feed. He still retains some of his old doubts, and with the same feed and the same speed he puts in the old tool, after grinding it carefully, and is really disappointed when he finds that the old tool burns and gives out in running less than one-twentieth of the time that the new one did. He goes to the blacksmith's shop and has the old tool redressed and rehardened, and tries it again, with about the same result. One more doubt remains in his mind, which is that that when this new tool is redressed a few times it will lose the qualities that it now shows, but he finds that it shows no difference in the results after repeated redressings.

Sam Brown is now convinced that there are still some things to learn about tool steel, and he will be a man who will try any steel in an intelligent and fair manner, and find out the limit of its capabilities. The result is that he consequently becomes a much more valuable man than before.

Then there is the other type of man who wants to try every steel that is offered without regard to price: and because he finds that some tools that he made of cheap steel stood as well or better than those that he made of a high priced steel, he labors under the delusion that he can get the same result right along from this steel, and that the man that had to charge a high price was making a very large profit. It does not occur to him that the bar of higher priced steel may have come from a store where it was placed to fill all sorts of requirements, to a certain extent, and the bar of the cheap steel was made of a temper more suitable to the work on which the test was made. The fact is unknown to him that the steel maker who made the higher priced steel could make him a bar at the same price, of the right temper, to do double what the cheap steel did.

The writer has met good mechanics who have said that they wanted a steel of which they could buy a bar and cut off a piece for any sort of a tool, and have it work all right in each case. One of these men was so set in his ideas that he bought octagon steel for all his tools, and gave, as his reason, that he knew that all octagon steel was forged and not rolled. This man insisted in making his lathe, planer and shaper tools from these octagon shapes by having his smith forge them into the flat shapes required. He also made taps, dies, milling cutters, reamers, chisels—in short, all tools from these octagon bars.

A salesman once persuaded him to try some flat bars of same grade, made especially for lathe and planer tools. Having received the bars and cut off enough for three tools, he had the smith forge the tools and harden them. These three tools cracked badly in hardening, and then he fastened them to the bars and returned them to the steel maker with a letter saying that they had turned out just as he had expected, that he was sorry that he allowed the salesmen to tell him his business, and that in future he wanted nothing but octagon bars.

The tools when examined showed that they had been forged full of strains by forging at an improper heat, and that they had also been badly overheated in the hardening. As a result of this man's notions, he spent about 40 per cent. more for steel than he needed to have done, made lots of extra work for his blacksmith, his men had to grind at least three times where once would have done with the proper steel, thereby wasting time and wearing out the grindstone. He had to renew his taps and dies often, and all hard cutting tools at least three times where he would once with the proper tempered steel for each

kind of tool. This man employed about twenty-five hands, was his own superintendent, would not try self hardening steel because he could not get octagon shapes readily, worked hard and faithfully ten hours a day, and wondered how some of his competitors managed to take jobs at the prices they did and live.

Again, we have a man with a process of treating the steel that will make cheap steel as good as the best. Usually, this man is a first-class blacksmith as regards forging, and his father before him has had handed down a receipt for a bath for hardening, or a compound to apply to steel while hot, that will impart all sorts of wonderful qualities. To disturb this man in his delusions is actual cruelty, and the man who is first to dispel his ideas is not apt to derive much benefit from so doing. Those, however, who come after may do so, as he suddenly awakes to the fact that the steel makers have been making progress since his father, grandfather or great grandfather discovered that certain chemicals did improve the very un-uniform bars of blister steel that were used in their day.

It may safely be asserted that the ignorance of steel consumers in regard to how to get the best for the purpose, and out of the best all that is in it, has laid the foundation of many fortunes made by numerous makers of tool steel. It may also be safely asserted that this lack of knowledge in many shops has resulted in about five times as much steel being used as should be consumed, and has cost thousands of dollars in renewing tools, in wasted labor with poor tools, as well as the time spent in changing, grinding and waiting for tools.

If you have a blacksmith who will insist in drawing the temper to a straw color or lower, on all sorts of

tools, you waste your money in buying high priced, high carbon and high alloy steels that require hardening. Get him just two grades, as follows: A good grade of ordinary steel for such tools as chisels, sets, drifts and all tools subject to blows from hammers or sledges; and for turning, planing, slotting and all sorts of forged finished cutting tools get him a self-hardening steel, or, if he is at all susceptible to instruction, one of the new high speed steels that have recently come on the market. On water hardening steels, however, it will be a waste of money to pay high prices as long as he has the notion in his head that all tools require their temper drawn until the color shows.

Another type of man whom the lay buyer has to contend with is the man who has the idea that the higher the carbon the better the steel, and on this idea insists upon specifying the carbon wanted for every piece of steel for which he puts in a requisition. The less you attempt to instruct your steel maker about carbons the better off you will be when you figure up your steel bills. Just tell the steel maker what you are going to use the steel for, and tell him that you want the best for the purpose named, and, if he is one of the leading makers, he will give you the right temper for the tool named.

Do not go and use this steel for some radically different purpose than you specified, and when it fails blame the steel maker. If you want to use it for all sorts of tools, tell him so and he will send you a bar that is intended for general purposes, just the same as he sends the dealer who sells it for all sorts of uses. A general stock temper and a special temper for a special purpose are radically different things. One is intended for all sorts of users and the other for skilled mechanics.

The man who wants a high priced steel for all sorts of tools, made of water hardening steels, must be reckoned with in a different manner, and he can waste considerable money on his hobby. If he is making expensive tools for cutting purposes, no matter what kind, give him the best for the purpose. If he is making tools from it that have no cutting edge and are not hardened, such as forces and large, soft punches, etc., or plain parts of machinery that simply require a hard wearing surface, they can be safely made from low priced tool steel furnished by reliable manufacturers. Especially is this so if the manufacturer is told what the steel is required for.

Nearly all large manufacturing concerns have many places where they can use a reliable brand of cheap tool steel to good advantage for other purposes than for expensive tools and for labor saving tools, but considerable discrimination is required to keep this steel separate, in its place, and out of the hands of men to whom steel is steel without regard to grade.

There are many more stumbling blocks that the well meaning buyer, who has not had practical experience, will come across in shop practice, but to enumerate and explain how they occur would occupy too much of one's time and exhaust the reader's patience; suffice it to say that the following chapters give an insight into many of the complaints that come to the purchasing agent, and the reason for many of these. There are many more that are not mentioned at all that the buyer will know how to deal with if he reads this entire work carefully from preface to finis, and still many more that are beyond the ken of the writer or any other mortal man.

The steel industry is an ever changing one, rapid strides are being made in new fields, and many old the-

ories are being upset. Up to the present time, however, the laws of nature still hold good in regard to making good, reliable, labor-saving steel. It still requires good iron to make good steel, uniform iron to make uniform steel, and high skilled workmen who can command good wages to make it right, even with the best iron and appliances. As a rule, no defective steel should be allowed to get to the customer who pays for a good article and is entitled to have it. For labor saving tools the best is none too good, and will always be found the cheapest in the end.

HOW THE VARIOUS STEELS ARE MADE.

CHAPTER II.

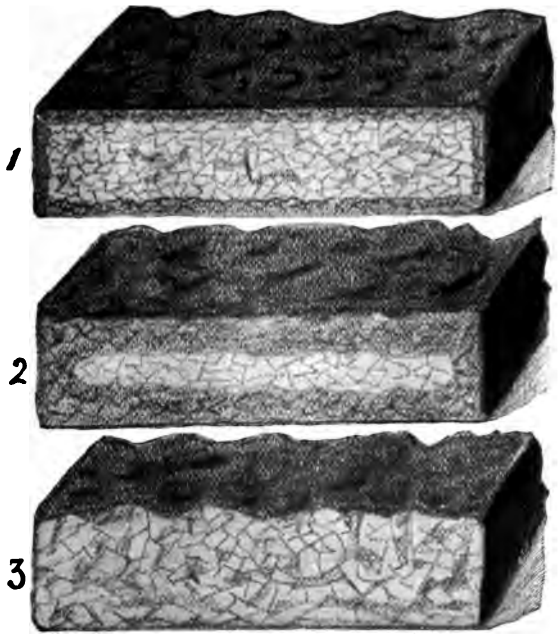
The steels on the market at the present time that are worthy of mention are made by three different processes, and are mentioned in their order as they stand in relation to tool steel as follows: Crucible cast steel, open hearth steel and Bessemer steel. Each of these processes is subject to some variation according to the locality where the steel is made. Two different kinds of crucibles are used largely, also several kinds of open hearth furnaces and Bessemer converters, which are claimed to be improvements on the original invention. As this work is devoted to the subject of tool steel, it is the crucible process that interests us the most, as up to the present time this is the only process that has enabled the manufacturer to produce a steel that any one can afford to use for expensive tools or ordinary tools in the hands of a skilled man.

Some extravagant claims have been made by various makers of open hearth steel for their especial product of open hearth steel for use in tools, and one or two makers have succeeded in producing exceptional results. But any consumer who has been rash enough to try open hearth steel to any considerable extent has found it an expensive experience, and has been more solidly converted as a user of crucible steel. In fact, his experience is usually so costly as to make him very loath to try any more experiments, even when approached by reliable

firms, who, perhaps, could have saved him considerable in his labor account.

That the uninitiated may be better able to comprehend the extent of the injury that these new methods may work and why they work them, it may not be out of place to describe briefly these three processes employed principally in the making of every kind of steel now used to any extent for tools. The oldest known method of making steel for cutting tools, weapons, etc., that we have any record of is still employed in the mountains of India by the natives to a small extent, and is known by the name of Wootz. This is made by taking small balls of iron, refined by working, and placing them together with quantities of charcoal in ovens made in the sides of hills. This is fired and repeatedly renewed until the iron becomes impregnated with the carbon from the charcoal. Very little known improvement was made on this method as far as quality was concerned, though many improvements were made for converting in larger quantities, until the middle of the eighteenth century, when Huntsman, of Sheffield, conceived the idea of melting the converted steel in crucibles in order to get it more uniformly carbonized.

Previous to this blister steel (so called from the blisters that rose on the bars during their converting process) was made by refining iron by the puddling process and forging it into bars known as muck bars. These bars are placed in converting furnaces with charcoal, as in the case in making wootz. In this process it was found that some bars took up considerably more carbon than others, and not uniformly in each bar, varying with the quality of the charcoal or other conditions. Some bars were impregnated only slightly, while others were saturated clear



Cut No. 1.

Three samples of blister steel, so called from the blisters shown on the surface. No. 1 is what is commonly called a spring heat. No. 2 is what is commonly called a shear heat. No. 3 a steel all through heat. The penetration of the carbon into the soft refined iron is shown by the darker outline around the outer part of Nos. 1 and 2. Of course, when any of these are melted together the whole melt becomes uniform.

through, and others about one-quarter way through from the outside. (See cut No. 1.)

Of course, this made it necessary to sort them out and grade them for the various uses for which they were best adapted, and, although the utmost pains were employed, it was impossible to obtain the uniform results desired by skilled users.

It was the old story over again—necessity became the mother of invention. If Huntsman had been able to make from blister bars springs that he could have depended upon he would never have troubled his head about inventing the process that was destined to revolutionize the steel industry and make Sheffield famous the world over as the place where the most uniform and reliable steel was made. No other method has yet been found for producing a uniform steel that the user can have implicit confidence in, though numberless attempts have been made to this end; and it may be safely asserted that all the reliable makers who make steel worthy of being used for expensive tools still employ this method.

In the earlier part of the last century the elder Mushet patented an improvement on this method, which consisted in preparing the medicine (carbon, etc.) carefully and putting it into the crucible with the refined iron, in order to do away with the expensive and slow process of carbonizing by the cementation process. He claimed that the carbon would be absorbed by the iron just as well in the crucible during the melting process as could be done by the baking process of first making the blister steel. There is no doubt that he produced some remarkable and highly satisfactory results by this method, and it is also beyond question that he failed to produce as uniform results, but the fact that it greatly cheapened the process of

making steel induced many makers to adopt it, and it is still in use.

Later, to do away with the expensive and very troublesome process of refining and purifying the medicine, Hawkins and Heath patented the process of adding the crude materials to the charge of iron, claiming that all the impurities would be thrown off in the flux during the melting process. This has been shown to be erroneous, and is one of the chief causes why so much unreliable steel finds its way into the market from the mills of the manufacturers who think more of the present profits than they do of building up a reputation. One thing has been settled beyond dispute, and that is that the Huntsman process is the only one known at present for producing uniform and reliable cast steel, and to do it with this process only the purest and best irons can be employed.

The open hearth process is an attempt to produce results in a cheaper way, and instead of making small quantities at a heat, as must be done by the crucible process, it is sought to produce from five to fifty tons at a heat, the latest modern mills being equipped with open hearth furnaces of the latter capacity.

This process, while unquestionably an improvement on the Bessemer process, as it does away with some of the objections raised by that process, has fallen far short of what its original inventors expected and claimed for it in comparison with the crucible process. While it has proved a valuable and useful invention for making a good quality of material for structural shapes, rails and boiler plate, and the numerous shapes of steel that have to a large extent replaced refined iron, it has proved a failure as far as producing a high grade of tool steel that could be relied upon for all sorts of tools.

The only high grade material that has been produced with its aid in the shape of tool steel is made in Austria, which has to be remelted in a crucible after being produced by the open hearth process. This steel has given very satisfactory results in some kinds of tools, and is chiefly used by those who are willing to pay a high price to secure the best results. For an all round steel it is easily equalled by several of the leading English and American makers.

The open hearth furnace consists of a basin-like structure of fire brick with either a basic or acid lining, which is charged with the iron to be converted. Over this a strong current of gas and air is blown, and a high heat is produced. In this way it is claimed that the impurities are removed by combustion and by oxidation of the blast as they rise to the surface, and the refined iron is ready to receive the charge of medicine and become thoroughly mixed by the continued blast. The modern furnaces are so constructed that this blast can be controlled and re-reversed. It is claimed that this process does not impart so much oxygen to the steel as the Bessemer process, where the blast is forced through the metal instead of over it.

The Bessemer process consists of melting iron in a cupola, or special furnace for the purpose, and drawing it in sufficient amounts for charging the Bessemer converter, and then in blowing a current of air through the charge from the bottom. This blast of air has the effect of largely increasing the temperature of the charge, and all the foreign matter is either burnt or blown out (except the oxide left by the air passing through). When the proper heat and condition are reached the converter is

tilted from the blowing position, the medicine is put in and the blast again applied long enough to mix it thoroughly.

Sir Henry Bessemer expected to revolutionize the tool steel industry with this invention, but instead revolutionized the puddled iron business, as Bessemer steel can be produced much cheaper from pig iron than a good brand of refined iron can be produced. As far as producing tool steel was concerned, the Bessemer process and all the attempted so-called improvements on it have been a dismal failure. There are numberless kinds of both open hearth furnaces and air blast converters that have been brought out since the original invention, but none of them have accomplished much toward overcoming the objections that existed in the original invention. Indeed, none of them have begun to approach the crucible process in uniformity and reliability of product. Both may be considered failures as far as the users of fine steel for expensive tools is concerned, but mammoth successes as far as their utility toward doing away with the expensive and laborious process of making refined iron is concerned, the most important product of both being railroad rails and structural steel.

WHY GOOD STEEL IS HIGH PRICED.

CHAPTER III.

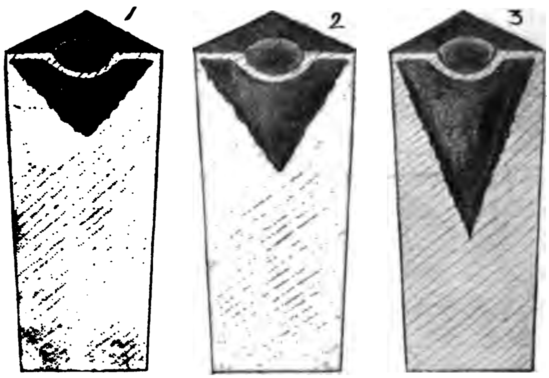
The question why good steel is high priced has been asked the writer repeatedly by buyers who did not evidently comprehend the amount of detail and endless care required to produce a bar of steel that an honest manufacturer could honestly warrant to be what his customer desired.

In the first place the iron used should be of the best and most costly kind, the price of the raw iron alone being much higher than the figure at which some of the so-called best cast steel is sold for. The production of this iron is limited, and the best known brands at the present time come from Sweden. Great efforts have been made to find a substitute for Swedish iron, as the demand from the makers of high grade steel throughout the world has made the price high; so much so, indeed, that an honest maker of steel finds all the advantages of improved methods offset by the increased prices of his raw material. Those who are not so scrupulous use this point to demand high prices for their inferior article.

This is only the first cost, and, to a manufacturer who is trying to make the best possible and who is satisfied with a fair profit, only a part of the cost of production. The most skilled, and consequently the high priced workman, must be employed from start to finish, and the utmost care be used through all the various treatments accorded to the bar from the time that it enters the mill

as a muck bar until it leaves the mill as a finished bar of steel ready for the tool maker.

The melter must use care in weighing out the proper amount of iron and medicine, must see that his crucibles are in good shape before charging, must be sure that the steel is properly melted or killed before the pots are withdrawn from the furnace, must be certain that the flux and all sediment are carefully cleared off the top of the molten steel before teeming, or pouring into the mold; must be



Cut No. 2.

Three half sections of three different ingots of different tempered steel, showing how the ingot settles in the middle in cooling. No. 1 being the mildest and No. 3 a very high tempered one. This shell above the line of the bottom of this depression is broken off before the ingot is forged into bars. This operation is called topping.

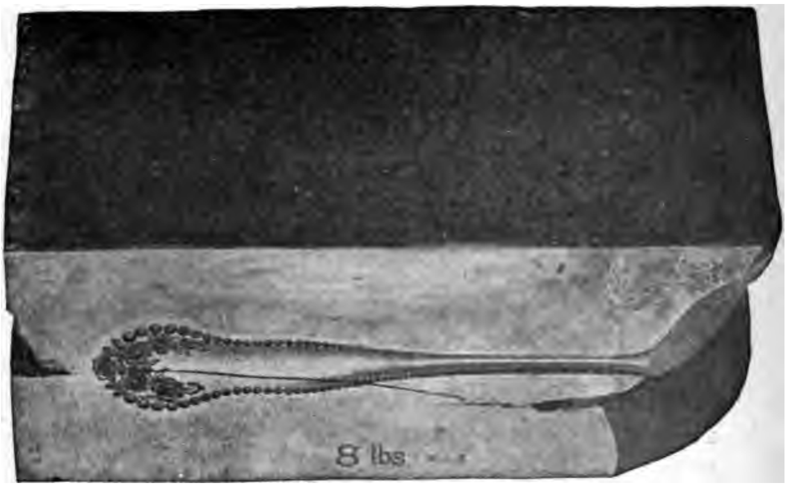
positive that it is poured in a continuous stream without stopping, and that it is at just the right heat when poured. The mold must be in the proper condition and stand right in order that a good ingot may be produced. When this ingot has cooled the clamps are knocked off the mold and the ingot goes into the hands of the most important man

about a steel mill, who is to decide what sort of bars and for what use the ingot is best adapted. This is done by topping the ingot, which consists in breaking off the top hollow shell, caused by the ingot settling in the middle in cooling. (See cut No. 2.)

This topping gives a fractured surface from which the temper of the ingot can be determined by an expert by looking at it. But to avoid all chances of mistakes one of the pieces broken off is put into the hands of the chemist for analysis by all conscientious manufacturers. If the chemist's report agrees with that of the ingot inspector the ingot is marked and started through the remaining processes necessary to produce the shapes required by the market.

The next operation is known as the welding heat and the welding. This is done by heating the ingot thoroughly through to a high heat, and hammering it under a heavy steam hammer, which operation produces what is known as billet. This is marked with the corresponding temper mark that was on the ingot, which mark must follow each particular ingot all through the mill and be placed on each and every bar made from this ingot to avoid mistakes of getting tempers mixed. The billet then goes to the finish hammerman's heater to be reheated, and is hammered into bars between smooth surfaced dies. This operation is called finishing, while both operations required to reduce the ingot to a billet and rough bars are called tilting. The first heat and operation is sometimes called welding the ingot. Some bars have to be reheated and tilted several times before being finished, and the utmost care has to be taken each time it is heated by the heater that it is not injured. The hammerman must use care and skill to avoid laps, cold

shuts, seams and bursting, or making a spongy or hollow center. The finished bars then go to the inspection room, and a piece is broken from each end to enable the inspector to examine the fracture at each extremity of the bar, and detect any faults such as pipes, hot or cold short grain. (See cut No. 3.)



Cut No. 3.

Teaspoon die, three-quarters actual size. $1.75 worth of steel, $35 worth of labor. Broke in hardening from interior defect. See Cut No. 4.

The bar is then examined from end to end for laps, seams and cold shuts, and if none of these are found, it is passed, and the heater and hammerman are presumed to have done their work right, and to have used due care in all the operations. (See cut No. 4.)

Cut No. 4.

Two pieces of the teaspoon die, shown in Cut No. 3. The cause of the break is here plainly shown to be a piped defective center.

Cut No. 5.

Broken section of a coal cutter used in a very expensive machine for cutting coal in the coal mines. These cutters are made of cheap steel, owing to the competition among the makers of these tools. The reason why the cutter broke is plainly apparent to the reader, a piped center.

The steel bar, or forging, is then properly marked and labeled and sent to the consumer, the warehouse or the dealer, as the case may be.

It will be seen from the above that trustworthy and skilled men must be employed in all the operations mentioned above, and that even more than skilled men are required, men who feel a personal interest in their work. Such men are not hired cheaply, yet when honest results are compared they are found to be the cheapest. When you buy extra or special or double refined steel you pay for this kind of labor. Be sure that you get it in the product you buy, and you will then appreciate the saying, "the best is the cheapest," and nowhere in applied mechanics does this apply with as much force as to tool steel. The reverse applies with equal force—that is, cheap steel is dear at any price, and it may be safely said that more expensive labor is wasted on cheap steel than would purchase an ample supply of the very best. (See cut No. 5.)

The foregoing shows that it would be impossible to get satisfactory work from dissatisfied men, and under paid men are always dissatisfied men. The melter, the ingot inspector, the heater, the tilter and the finish hammerman must each feel an interest in his work, enough to see that it is done right, and the inspector of the bars must have ability enough to know whether they have done their work right or not. The skill required in each of these positions calls for years of practice coupled with a natural gift of good intelligence. The demand for this class of men far surpasses the supply, yet honest manufacturers can employ this class of men and the best material, and supply steel for ordinary purposes at 12 to 15 cents per pound, with a fair profit for themselves, but cannot do it for less.

Steel for special purposes can be made to cost much more, so much so that 50 cents per pound would not be unfair. These high-priced steels, however, are not intended for general purposes, but for special tools for which they are especially made.

CHAPTER IV.

WHY CHEAP STEEL IS EXPENSIVE TO USE.

The many brands of so-called best cast steel offered to the consumer at prices, in some cases, far below the cost of the cheapest grades of steel iron required to make a reliable tool steel are the most expensive steels that any manufacturer can use who makes his own tools and supplies them to his skilled mechanic to use. The reason is that it costs as much in labor to make a tool from cheap steel as from the best, and when the tool is made it may be worthless, or nearly so, and the chances are ten to one that it will have to be renewed from three to five times, where one made from a higher grade would be renewed once.

As there are very few tools in use that the cost of labor of making is not several times the cost of the steel from which they are made when made of the best grade, it does not require any great amount of mathematical ability to figure out which is the cheaper to use for expensive tools.

We have known a contractor to buy cheap steel for chisels and drills, and his men have spent time enough in stopping and waiting to have them redressed and going back and forth for this purpose to pay three times over for the steel used by another contractor. The latter paid over twice as much per pound for his steel and did exactly the same amount of work, of exactly the same kind, with just one-third the amount of steel used by the cheap steel

man, in weight. He accomplished the same amount of the same kind of work in a trifle over four-fifths the time used by the cheap steel man, and with four men less. This was done on a public building with two wings of the same dimensions. We leave you to guess which contractor made the most out of his job. We mention this because, of all tools made from tool steel, stone chisels and drills are about the cheapest tools to make that tool steel is used for. The object lesson is plain. (See cut No. 6.)

Cut No. 6.

A set of stonecutter's tools for which it will be found economy to use a medium priced, carbon steel.

There are several firms who make a business of manufacturing tools of all kinds other than the common forged tools for the market. Some of these use the best steel they can buy at the medium price. Others who compete with them use the cheapest they can buy, and sell their goods to supply men and other middle men at prices below what the others can afford to sell at. For instance, in one shop when a certain grade may be recommended for taps, dies, milling cutters and drills, etc., the buyer says that they do not make these tools, as they find it much cheaper to buy than to make them.

In another shop, where the work is of such a nature that they are compelled to keep tool makers to make the special tools which are not made for the market, the usual query is, " What have you got that will make good milling cutters, good taps, dies, drills, etc. A certain grade is recommended and the salesman secures an order with the information that they make all their tools of this description, and find that it pays to do so. They find that they get from three to five times the service from tools of their own make than they can from those they buy. While the tools cost more than they could buy them for in the market, they make them instead of buying them because they are compelled to keep tool makers anyway, and do not have enough special work to keep them busy all the time. They find that they are large gainers by so doing.

This should not be the case and would not be if it were not for the competition between cheap tool manufacturers with those who would make the best tools of the best steel if this competition and efforts to pay dividends on inflated capital did not compel them to resort to various methods that work to the disadvantage of their product and the injury of their customers. When one

takes into consideration the large variety of tools that are made from steel and how few tools there are the labor cost of which does not exceed many times the cost of the steel, it is astounding that so much cheap trash known as best cast steel should find a market.

There are known to the writer two firms in the same line of business whose output is about the same, and who each have about the same number of hands using tools. One keeps two tool makers and pays 15 cents per pound for his steel, the other requires five tool makers to keep the tools in working order, made from steel purchased at a price under 8 cents per pound base. If we were to contract to pay the tool makers required to keep up the tools and pay for all the good steel required for the amount wasted in extra labor of tool making from cheap steel, in extra amount of steel required, and for the time wasted in stoppage of work by broken and defective tools, and their replacement as well as the stock ruined and made scrap by said broken and defective tools in the shop using cheap steel, the balance in favor of the higher priced steel would be considerable. Volumes could be filled with instances of this kind that have come under the writer's personal notice, but the above will suffice.

The question might be asked, "If such is the case why do reputable firms make this cheap grade of steel and sell it for general use?" The answer is simple. Because the customers demand it and because life is too short to convince them that they do not understand their business, even were it policy to try. The reason for this state of affairs is this: in listening to those charlatans who are constantly bobbing up with the claim that they have found the philosopher's stone, and are prepared to make something out of nothing, the laws of nature which

apply to steel as well as to everything else are overlooked in the delusive desire to save running expenses.

A manufacturer starts out to make steel. He purchases an amount of the best steel iron; he secures the best workmen he can get, and starts with the determination to make a reputation for himself and his product. He finds that the bars ready for the market have cost in material and labor so much, and the gross value of his product with his present investment is so much. The latter must pay his interest on the investment, his fair profit and the selling expenses. When these are added to the mill cost of the steel he finds that he is compelled to charge 12 to 16 cents per pound to cover these items. He starts his salesmen out on the road to find customers, and instructs them to warrant the steel equal to any sold at a like price. The salesman reports that one company whom he was expected to interest are using a steel for which they are paying 8 cents a pound, and say that it fills their requirements. They are probably honest in their statement as far as they are aware. The salesman proceeds on his mission, and the next firm he calls on informs him that they are using a certain steel, and that they have all the experience they desire in trying new steels. They add that their experience has been very costly to them. They are paying the same price as this salesman charges, and can see no inducement in changing from a steel that they know all about to one that they know nothing of; but to soothe his disappointment tell him," if we have any trouble we will try yours next." He calls on another firm, and is met with the glad hand. The steel they have been using has turned out unsatisfactory and they want no more of it. They have spent over a hundred dollars in labor in making up a lot of taps

and dies, and find them all worthless when put into use. They tell him that the steel has worked well before and that this is the third lot they have had of it. It costs 8½ cents per pound, and they expected to save some money on their steel bill, but this last lot has cost more than they had saved.

The salesman asks them what kind they were using before this last kind, and why they changed, and is informed that they were using ——'s steel, and had used it for twelve years, but changed because they got one bar having a bad spot running half way through the center of it, and all the tools made from this bad part burst in hardening. About this time they were offered this last steel, costing a little more than half the price of the other. They tried it and it worked well, but not as good as the old steel. The tools were not as long lived in use as those made from the old steel, but as the new steel was nearly 50 per cent. cheaper they could not expect more than half the service.

When one takes into consideration the fact that the cost of making the tools out of both steels was the same, and that 5 per cent. more service would more than pay the difference in the cost of the two steels, the folly of this sort of reasoning becomes plainly apparent. Yet this is an every day occurrence that one too frequently finds.

But, to return to our salesman with the new steel; by dint of strong persuasion he succeeds in getting an order, and on his next visit finds a pleased customer with another order. On his third visit he is welcomed, but informed that his customer is trying another new steel at a less price, for which great claims are made, and that if it is as good as claimed to be they would save 5 cents per pound.

The steel maker, with the good intentions, becomes convinced that he must fall in line and make a cheap steel also, to supply the demand and enable his salesman to make it pay when traveling. And so it goes on. The manufacturer who has to send out men to introduce his goods must have competing prices for those who desire cheap prices above all else.

The demand will always control the supply, and it is the man who expects to get something good for little money who fills the world with knaves to supply his wants. Good bread may be expected from ground stone in the same decade that uniform and reliable steel is made from impure and ununiform iron, by cheap labor and cheap methods. The writer does not wish to be understood to say that no good steel is made at low prices, or that a cheap steel is not an economical steel to use for certain tools, but does say that, looking at the matter from the standpoint of shop economy, there is no steel made at the present time economical to use which can be purchased for much less than 12 to 16 cents per pound, and in a large variety of tools these prices can be exceeded many cents with great economy. That there are many good steels sold at low prices cannot be denied, and that some of these are far better than some sold at high prices is beyond question. No man knows what the future may bring forth in new inventions and methods for producing a cheap steel that is uniformly reliable and economical to use. That an economical steel to use for expensive tools must cost money is beyond dispute for the present. When some way is discovered of removing entirely the numerous impurities from cheap iron and adding to it enough native strength to make it equal to or better than, the present expensive steel iron we may expect to

produce a reliable, uniform steel at a cheap price—that is, of course, provided we can succeed in raising a class of steel makers who will be as content to work for one-third what their kind get at the present time, and feel equally interested in the success of their work. Until then we must expect to abide by the saying, "good goods demand good prices." And to nothing on the face of the universe does this apply with more force than to steel for expensive tools or labor saving tools of any kind.

HOW TO CHOOSE THE BEST FOR YOUR USE.

CHAPTER V.

How to choose the best steel for particular uses is one of the problems that has puzzled many a buyer who has listened to the conflicting claims of the various steel salesmen that have tried to convince him that they had the best. It is one of those points for which it is impossible to lay down fixed rules, though the following may be of some assistance to the conscientious buyer anxious to do the best possible for his firm.

If the tools that are to be used are very expensive, such as silversmith's stamping dies, a steel should be chosen made by the maker having an established reputation, and the medium price should be paid. This will

Cut No. 7.
Soup ladle die, one-eighth actual size. \$4.50 worth of steel and \$900 worth of labor. Made of steel costing 16 cents, base, per pound.

enable the maker to use the best possible material obtainable and the proper care required to produce a sound and uniform steel. The best possible results should be ex-

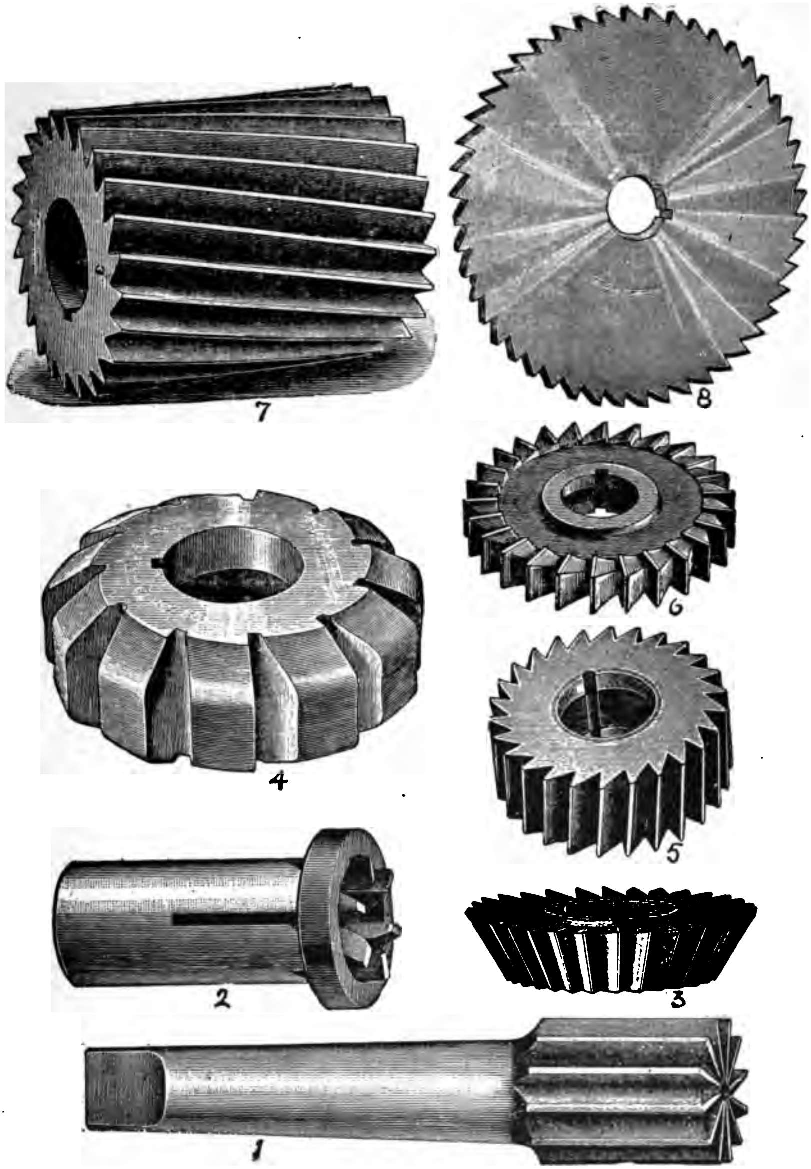
pected from a steel costing from 12 to 16 cents, base, per pound, as the steel required for this purpose is not of the nature to make it so expensive to make as that for many other purposes. (See cut No. 7.)

On the other hand, if your firm want a steel for milling cutters, taps, twist drills, etc., that they expect to use in their own practice, a steel made for this special purpose may cost several cents more per pound when made from the identical grade of iron as that employed for stamping dies. (See cut No. 8.)

A higher temper should be used, and consequently the steel costs more to make if made with due care and regard for the requirements of the consumer.

Again, if the steel is to be used in the machine shop by skilled mechanics for lathe, planer, slotter or certain screw machine tools that are of such shape that they can be safely hardened, the very highest priced steel made, even the high alloy steels, can be used with great advantage proportionate to their cost. Low priced steel, however, cannot be used to advantage by skilled workmen under any circumstances, and should have no place in the tool room of any well-regulated firm employing only skilled men. There exist certain conditions where cheap steel can be used with economy, and it is referred to in another place in this book under a separate heading. (See cut No. 9.)

Enough has been said on this subject to enable the buyer to see that he must use the best judgment, according to the requirements of the uses to which the steel is to be put. To mention all the various uses that steel is used for would take more space than can be devoted here. If the buyer himself is a steel worker he will perhaps not need any advice from the writer about how to choose the



Cut No. 8.

Eight different shape milling cutters, which it is economy to make of a steel at least as good as any of the extra and special brands, and which it is still greater economy to make of the best brands obtainable.

steel best adapted to his use; but, on the other hand, if he is a young man employed to do the buying, these points will perhaps assist him:

Cut No. 9.

Die for stamping the back of a mirror. $12 worth of steel and about $400 worth of labor used to produce this die.

There are numberless humbugs in the steel business, as well as some makers who are after present returns, re-

gardless of future reputation. This may assist him in discriminating and place him in a position of being, in a measure, independent of the mechanic, who may be either too prejudiced from past experience or too stubborn to learn all that he should know in order to be abreast of the times when improvements are being rapidly made by both the steel maker and the steel consumer.

That manufacturing firm is most fortunate which has a conscientious purchasing agent and a thorough, well posted master mechanic working in co-operation with each other to get the best. A very common mistake that many buyers make is, when trying a new steel, to try it in some place where the steel that they are using will not stand (and perhaps no other would), and then condemn the new steel for failing just as the old one did.

If you have a place where you are having trouble in getting the tools to stand up and do the work desired, do not take the new steel and put it into the hands of a workman that is not well enough acquainted with it to get the best results out of it, and expect to overcome your trouble in the first trial, and condemn the steel forever if you do not. If it is of vital importance to you to overcome this trouble, and you feel that you have no time to experiment with it a little in other places where you can get a comparative test between the steel you are using and the one being tried, just give the steel maker all the particulars to the minutest details, and see if he cannot help you out of the difficulty by making you a bar of special temper, such as he thinks will answer the purpose. If he fails, and others fail, you may safely conclude that you are asking too much for any steel to stand, and you will remain in the dark as far as knowing whether any of the steels tried were better than what you were using. Should you

earnestly desire to find out whether the steel offered is superior to what you are using, buy a bar or two for use in several different places where you are having no trouble at all, and see if it does any more work than that you are using. If it does, you will become convinced that the salesman had some basis for his claims, and perhaps he can help you out in places where the other will not stand at all, or as well as it should.

The writer, to illustrate how this works, will cite an instance that came under his notice. A salesman called at an office of a large manufacturing concern whose trade in tool steel was extremely desirable and was informed that they were well satisfied with what they were then using and did not desire to make a change. They had, however, one place where they could try a piece of steel where they were not getting as good results as they wished. The superintendent was called and requested to show the salesman what was required of the steel. He led the way into the forge shop and stopped beside a pile of broken dies that had been used in stamping 14-gauge cold rolled strip steel into a shape resembling an inverted letter W, and with the sides curtailed and curled up at the edges. The width of the piece when stamped was 1¼ inches. This required, be it noted, a deep impression in the lower die, flanked with two more hollow ones, separated from the center by ridges. Of course, the upper die was the reverse of the lower, with allowance for the thickness of the metal.

The salesman remarked that it was a very severe test on steel, and was informed that it was the only place that they cared to try a new steel, and that if it worked well there, they might try it in other places. He took the order, subject to the approval of the firm he traveled for,

and they, in their eagerness to get started with the firm in question, forwarded a bar of what they thought most suitable, notwithstanding the fact that the salesman had given details of the requirements fully. Like all others tried the steel failed after striking a few pieces, and the salesman was informed when next he called that the steel he was selling was no good for their work.

The salesman called on this firm periodically for over a year without getting the least encouragement more than being told "they had tried the steel once and did not find it any better than others they had tried." About fifteen months after the experiment related he called, as part of his regular duty, without the least hope of receiving an order. To his surprise he was invited into the sanctum and politely requested to wait a few moments while the superintendent was sent for, as he wanted some steel, and requested that he be called in on the next visit of the salesman. (See cut No. 10.) When the superintendent arrived he asked the salesman if he sold "So-and-so" their steel for a certain purpose, and on his reply in the affirmative said that he wanted some of the same kind. He then ordered about twenty bars. After it had been put in use he found that he could do from five to six times the work that they had ever acomplished before with any tool made from any steel they had ever tried.

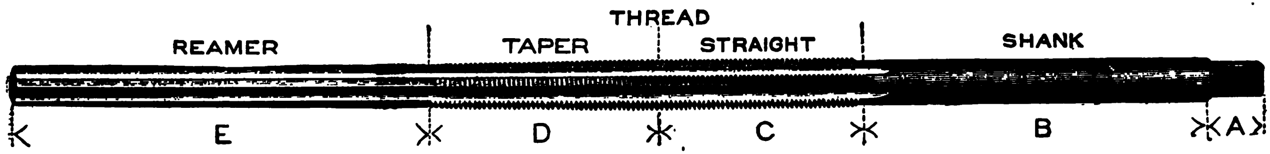
It will be seen from the case stated above that while the consumer might not be having any trouble with the steel he was using, he might have increased his output and saved tool-making expenses if he had tried the other steel in some of the places where he was not having trouble instead of a place where he had been unable to find anything that would stand satisfactorily, and which he had to abandon ultimately. And he had to do this

Cut No. 10.

A set of three-lipped hollow drills for counterboring. One-fifth actual size. With them is shown a two-lipped drill.

difficult shaping by the hot process, and finding the extra labor entailed by the extra polishing did not cost half what it cost to constantly replace the stamping dies for the cold rolled steel, to say nothing of the amount of more expensive stock spoiled over the almost infinitesimal amount wasted in the hot process.

When trouble is experienced in any department of your works in securing a reasonable amount of service from tools take some reliable steel maker into your confidence and tell him your requirements fully, and the chances are, ten to one, he will help you out. (See cut No. 11.) But if the tools are extremely expensive to make try the steel first in some of the cheaper tools to allow your smith to find out what sort of a heat it requires to be at its best and how it works in the forging, etc., that he may be able to harden the more expensive tools to the best advantage when they are made from it. If you are making a diversified list of articles for the market, where a large variety of machines are employed, you will find that you can use a large number of tempers and grades to great advantage to yourself, providing your master mechanic is "up-to-date." To enumerate all the grades and tempers best adapted to the thousand and more uses that steel is used for in the shape of tools, parts, etc., would fill a small volume; but the foregoing will serve to give a general idea of what is best to choose. (See cut No. 12.)



Cut No. 11.

This cut shows a stay bolt tap 4 feet 6 inches long, having reamer, taper and straight thread all combined. Should be made of an extra quality of steel. It pays also sometimes to make these of one of the high alloy steels, if they are to be used by skilled mechanics who take good care of them. Have been hardened by heating in a heating furnace inclosed in a piece of pipe.

Cut No. 12.

Three shell reamers. Two made of solid steel and one with adjustable teeth, which should be made of a water-hardening alloy steel; the holding head should be made of a hard, cheap grade of crucible steel.

PLACES WHERE CHEAP STEEL CAN BE USED TO ADVANTAGE.

CHAPTER VI.

There are many places where low priced crucible steel can be safely used with as good results, as the higher priced steels intended for expensive cutting tools or costly tools subject to severe work, such as engraved stamping dies, master dies, etc.

Some railroad track masters say that for their track tools they have obtained better results from a low priced, mild steel than from high priced steel made especially for their use. The reason for this is plain. The smiths who made the tools from the better steel did not take sufficient pains in making them, and the various smiths along the road were equally careless in redressing them, so that, in fact, the better steel was not so well adapted to standing the misuse as the cheaper and probably milder grade. In all probability the better grade was stiffer and more calculated to stand up longer, when properly treated, than the other. If so treated, the writer has not the slightest doubt that it would do from eight to ten times the work per tool that the cheaper was capable of doing. But to insure this right treatment, however, would put the company to more expense and trouble than they would save, according to their reasoning. While, on the other hand, if this steel was maltreated in making the tools, the extra wearing quality placed in the steel by the steel maker would become an element of danger to the users of the

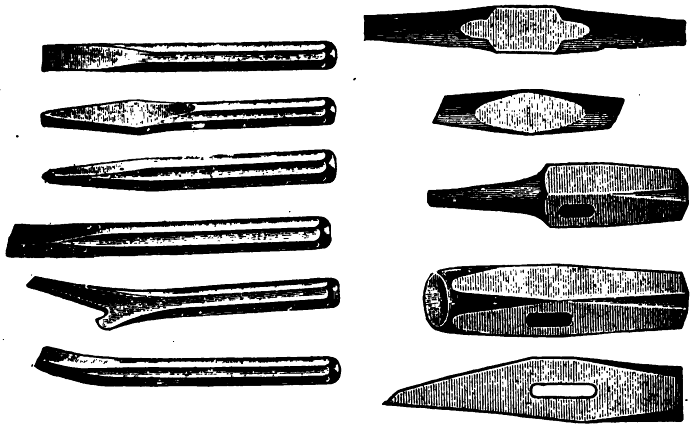
tools by breaking in use from being so maltreated that strength of the steel was destroyed.

The only high priced steel that has been successfully used for track tools is one that is made of such a nature that it can be worked almost like iron and welded with sand. Its chief claim to excellence is that it is made from one of the best brands of Swedish iron, which in the bar iron sells for more than the cheap steels. It is the toughness and uniformity derived from this source that gives it the preference over steels sold for less than half its price. The chief point in its favor is that it will stand as much or more than the cheap steel, which latter, we have shown, will stand more than a fine, higher priced steel made especially for the purpose. Another fact in its favor is that the quality of material it is made from, combined with its mildness, prevents all breakages, but does not prevent tools made from it battering down quickly, as was intended by the maker of the better grade mentioned above. If one meets these conditions he must be governed by circumstances rather than theory usually applied to tools. Flatters, swedges and about all the non-cutting tools used in the blacksmith's shop and the boiler shop do not require a high grade of steel. (Cut No. 13.)

A cheap steel made by reputable makers can be used with satisfactory results from an economical standpoint—plain parts of machinery, where a clean wearing surface free from hard and soft spots and uniform wearing qualities are desired, found only in crucible steel, and not in cheap machinery steels. It may be well to explain this assertion as far as possible right here.

The writer does not pretend to understand the reason why, but any maker of high class wood working machinery or high speed grinding or polishing machinery

will confirm the statement that all the open hearth and Bessemer steel that he has used has shown a hard and a soft side when put in service in high speed shafts, so much so that it has worn out of a true circle after being a short time in use. For these parts low priced tool steel will do as well as the best, and prove superior to anything sold for less money. One wood working machinery maker of national reputation carries this idea so far that he



Cut No. 13.

Some of the tools used by boiler makers that require to be made of good steel.

orders all his crucible steel shafts and forgings made enough longer than the required length to enable him to cut off a piece long enough to be forged into a lathe tool of good enough quality to turn the shaft that it was cut from, and do it in a satisfactory manner. This is going further than necessary with a reputable manufacturer, and does not prove that the steel is crucible steel, as this could be done with open hearth steel.

Another place where cheap tool steel can be used to advantage is in plain parts that are to be hardened, where simply a hard wearing surface is wanted, and the parts being of such shape that no danger of cracking in hardening exists, these parts being used in such quantities as to make it an inducement for you to order especially for them. Low priced crucible steel can also be used in large stone breaking hammers, sledges, mauls, etc., with as good results as though a high grade of tool steel was used, unless this also was made especially for the special use; in that case the extra quality of iron used would probably give additional wear, but even then it is doubtful if the extra results would compare with the extra cost when the treatment given the steel in making the tools is considered.

Coal and earth wedges, as well as wedges for splitting logs, are found to serve as well when made of a low priced crucible steel as when made of the best, and many users of these tools say that they have found a cheap, mild steel capable of taking a surface hardness to be superior to those made from high grade tool steel.

This is one of the reasons, it is presumed, why manufacturers of tools for coal mines and certain kinds of cheap tools have taken up the use of open hearth steel for a large portion of the tools where crucible steel used to be required exclusively, and could be used with greater economy to-day in many places.

For large tools which are considered unsafe to harden in the regular way, and as a result would need to be replaced frequently, low priced crucible steel can be used with great advantage in cost over what would be best were the tool to be hardened properly.

Another place that it may be found best to use the low priced tool steel is for the tools used in bridge building, where a large force of men are employed away from the shop, and the tools are dressed in an improvised blacksmith's shop, and half of them lost in the river by careless workmen who would lose as many if made of the best steel obtainable. The same rule applies here as to the track tools on the railroad.

Of course, in a large body of men some will be found who take care of and appreciate a good tool, and take pains in keeping it as long as possible. If supplied with a kit of tools at the shop they will take care of them out on a job and return with them all; these are the men to whom it pays to give the best, and the others are the ones to whom it pays to give the cheapest, as the tools used by the latter are never worn out, but are lost before the short term of service expected of them has expired.

If you are manufacturing for the market tools of all kinds that have to be sold in competition with others, without regard to gaining a name and reputation for the product, you are compelled to use the lowest priced cheap steels that can be used without a disastrous percentage of loss in manufacturing, owing to the lack of uniformity found to a larger extent as the price lowers. Should you be making tools on which you hope to establish a reputation and build up a business that has honesty for its keystone and quality for its foundation, this rule does not apply.

There are many more places where low priced tool steel can be used to advantage over the higher grades. In most of these places various grades of open hearth, Bessemer and other special process steels have replaced crucible steel entirely, and in others manganese steel and

special process castings have taken its place to a large extent.

Such tools as dredger pins, stamps and shoes used for crushing quartz and other rock—these all used to be made from crucible tool steel of a good grade, but competition and lack of proper care on the part of the users in getting the best results out of the steel have created a demand for something that required less skill to work.

GRADES OF STEEL FOR VARIOUS TOOLS.

CHAPTER VII.

The day has long since passed when the buyer could order a large sized bar of steel and have his blacksmith make from this bar all sorts of tools that might be required and be satisfied with the results obtained. The idea that the blacksmith could improve the steel maker's work by long and tedious forging of small sizes from the large ones is also "out of date." The blacksmith cannot improve a bar of steel produced by any of the leading manufacturers in texture, grain or in the temper by forging. If he will let the steel leave his hands as good as he received it, after shaping it as desired, he is a gem and a valuable employee of any manufacturing establishment where tool steel is used. The idea of long and repeated forging of steel has descended to us from the times when we were compelled to buy bars of "blister" steel and work them by forging up to the point now found in the poorest piece of steel offered on the market, in order to get the best possible results from it. The up-to-date manufacturer now wants to buy his steel as near the size that he is going to make his tools or parts as is consistent with cleaning the outside "scale" and the underlying "decarbonized skin." (See Chapter XII of Second Part.) He also wants the proper temper for the particular tool that he intends the steel for. He further wants the best grade or quality suitable and best adapted for the purpose he intends to use it for. And this question, properly considered, will prove a saving source in more ways than one.

Let us suppose a few cases, to make the matter plain, at the same time confining ourselves to every day practical illustrations. Take a machine shop, for instance, that is building power presses and all their accessories, such as punches, dies, forces, etc. Here we have large castings in the shape of beds and the upper frames and legs that have to be planed to fit together perfectly. The grade of steel that the man who runs the planer can use with the greatest amount of time saved, and yet obtain the results, is one of the new high speed steels that have recently been put on the market as improvements on the well known self hardening steels. The next best to use is one of the before mentioned self hardening steels, and the third on the list would be a grade of tool steel costing from 12 to 16 cents per pound. Should either of the above not be available, water hardening alloy steels could also be used successfully.

On rough, sandy scale of castings, however, it does not show up much better than ordinary carbon tool steel and is considerably more costly than the best grades of carbon steels. The high speed steel is recommended, no matter whether the planer runs at a high speed or not, for the reason it is best adapted for cutting through hard spots and scale, and withstands the heat generated in cutting and the friction of dragging back at the reverse of the planer. It will also plane a much larger surface without grinding, if properly hardened according to the directions that come with it.

We also have a man on a 36-inch lathe turning up the fly wheels. He also can use this high speed steel. If he has the requisite amount of intelligence and the interest of his employer at heart he can finish up three wheels in the same time required to turn one with the regular tool

steel; can also face up the hub with same steel and rough bore it.

We next have a man on the small planer planing up the steel gibs for the ways. We find that although he can use this steel with good results, in this place a water hardened alloy steel costing considerably less will do equally well at the speed at which this planer runs. It can be made into tools that are so shaped as to be used to advantage, while the high speed steel cannot, owing to the treatment that it requires in the hardening process prescribed by the makers.

The man who is turning the shaft can also use this high speed steel to good advantage if he has much to rough off. In finishing the bearings and in cutting the thread required the water hardened alloy steel will be found the best. For the locking key and dog a mild, cheap steel can be used, if made with the proper understanding by the steel maker of the use that it is to be put to, provided he is one of the reliable makers.

Should the purchaser of the press want it fitted up with punches, dies, forces, etc., and give instructions to furnish the best possible outfit for punching and stamping up large pieces from 30-gauge metal, for which he furnishes the drawings and other particulars, it will be safe to choose the right sized medium priced steel to weld on to a base block of soft machinery steel, and the same for the punch if the same is to be hardened. If the requirements are such that it is advisable to leave the punch unhardened, soft, common crucible cast steel will fill the bill as well as the most expensive made.

The die and punch being welded up and annealed, it is put on the planer and the back planed to a true surface with tools made of water hardening alloy steel. From

the planer it goes to the vertical milling machine, and the cutting edges of the die are milled to fit the template and the upper surface machined parallel with the back, or as the case may require. The surplus stock is then milled off the side of the tool steel part of the die and the top of the base to make a workman-like job of it. The tools for doing this can be made of the medium priced steel or water hardened alloy steel. It is a debatable point as to which is the more economical; much depends on the man that is using the tool and the judgment that he uses in working into the corners and through lumps of steel, scale and borax; any of these will spoil either cutter, no matter what steel is used, if judgment is not used. If a first-class mechanic is running the machine it may be safely said that the best obtainable brand of water hardening alloy steel will be found the most economical to use for all these end mills; but if the operator is simply an average man, the mills will probably do as much service if made from any one of the leading brands of extra, special or double refined tool steel.

A manufacturer of bolts and nuts requires a variety of grades to run his works to the best advantage. For the hot heading dies steel as good as is required could be secured at 8 cents or less, base in the bar. For the bunter or head forming punch it would pay to give twice as much in some cases, according to shape. For the hot punches self hardening steel is the best known at present. For the holding jaws in the punching and taping machines a mild, cheap steel that will stand case hardening will prove the best. For the reamers for sizing the holes in the nuts before taping the water hardening alloy steels will be found the best. For the machine taps, run in oil or cutting compounds, an extra grade of carbon steel will

be found the most economical. For the nut finishing tools for squaring and champering the water hardening alloy steel will be found the labor and time saver and to do the best work. The threading dies can be made from a good grade of double refined steel, which will prove the cheapest, especially if it is intended that they shall be worked over after becoming dull or worn so that they do not cut to size. For the hob taps there is nothing which bears comparison with the water hardening alloy steel. It will prove far ahead of anything made for this purpose, notwithstanding the fact that the material and the making both cost much more than the best double refined steel.

If the work demands the extensive use of screw and turret machines, about three kinds of steel can be used in the outfit of tools required in these machines, according to the shape and duty of the tools.

It is impossible to lay down regular rules to enable one to decide positively which is the best grade for the many purposes that steel is used for, owing to the different conditions that it is used under, such as varying treatments in making the tool and the fondness of many mechanics for applying some particular discovery of their own to all steel that comes into their hands for treatment. These men are inclined to be stubborn in their conceit and scorn any rules laid down by those who may happen to differ with them. It never occurs to them that steel makers know anything about making tools, or hardening and tempering them, and as a consequence they judge all steels by the results they get after they have applied their own peculiar ideas. If the steel is of such a nature that it cracks, or fails in any other way, the thought that the steel was misused by them never enters their heads, but they report to the " boss " that the steel was no good, etc.

Many of these men, deservedly called steel cranks, are first-class workmen in other lines than hardening and tempering steel, and their employer has pampered their vanity to a point where they have long since decided that they are way up on everything pertaining to their branch of business—steel hardening and tempering especially.

The writer has known a blacksmith who could forge the nicest shaped tool that ever pleased the eye of a tool maker or machinist, and more of them than two ordinary men could do in the same time; yet this same smith could not harden and temper a tool that would stand as long as it took him to do it. The man in question was hired to dress the tools for the machinists and tool makers in a large shop and did the work that it required two to do after he had graduated. The wise ones among the tool makers used to have him forge their tools and anneal them under the pretext that they wanted to "file the tool up" before hardening. In this way they could get the tool forged in good shape and before the life had been burned out of the cutting part, and take it to another forge and harden it themselves, thereby getting a good tool. It was the pride and boast of this smith that he could forge any sort of a lathe or planer tool at one heat and shape it as good as the best. The result may be easily guessed.

After forging at this high heat and smashing the tool into shape at one heat, the tool was again inserted into the fire without having a chance to cool and relieve any of the severe strains caused by the forging. It was then immersed over the cutting point in cold water. The superintendent had made this man so vain in praising him about his expertness in forging that it would have been dangerous to insinuate that his ability as a tool

dresser ended with the forging; yet such was the case.

If you have this sort of man to make your tools, buy him self hardening or, better still, the new high speed steels for all tools where it can be used, and for the ordinary steel buy anything that is cheap, for he will make as good a tool of the poor as he would of the best.

The reader will see from reading the foregoing that he must be governed largely by circumstances in choosing the grade of steel for his use. It is the man who uses the steel who must be taken into consideration. If he is first-class and progressive give him the best that money can buy. If he "knows it all," give him what he asks for, if his work in other directions makes him valuable enough to offset his ignorance in this direction.

One has to consider the general results in manufacturing successfully. Bear in mind the fact that a good man will make a better tool from poor steel than a poor man can make from the best steel, and the better steel you give a good man the greater return you will get on your investment.

THE UTILITY OF ALLOY STEEL. (OLD AND NEW.)

CHAPTER VIII.

In the year 1868 Robert Forester Mushet, in making experiments to secure a medicine to improve Bessemer steel while manager of the Titanic Steel & Iron Company of Coleford, England, discovered what has since been known as Mushet's special steel and Mushet's self hardening steel. This steel, while not adapted to general use, proved superior to any other known steel for rough and rapid turning and planing with heavy chips and rapid speeds, and opened up a new field in the steel industry which had not been explored before. Previous to Mushet's discovery it was assumed that all edge tools for cutting hard or soft material must be made from steel with the carbon best adapted to the purpose required. Consequently Mr. Mushet met with the usual amount of opposition and skepticism as well as ridicule, and nothing but the fact that he was a well known steel expert, as was his father before him, secured him a hearing. He lived, however, to see his steel called for from all parts of the civilized world, and to see nearly every other steel manufacturer of note imitate it.

These attempts at imitation and efforts to improve on it have resulted in the discovery that alloys of various minerals, combined with ordinary carbon steels, improved the cutting and wearing qualities far beyond what had been known before both in self hardening or air hardening steels and the steels hardened by the usual methods,

The result of this experimenting has produced a large number of water hardening alloy steels, as well as a legion of so-called self hardening steels, or steels that are hardened by simply exposing them to the air at a good heat after the tool was forged into the desired shape.

For thirty years no perceptible improvement was made upon Mushet's product, as far as self hardening steels were concerned, but many good alloy steels were evolved that required hardening according to the methods formerly employed with ordinary steels. These have steadily been so improved upon that they have become almost indispensable in all well regulated shops where the science of shop economy is practiced. These alloy steels have almost entirely supplanted the extremely high priced double refined and special steels for all kinds of forged tools and those made from flat steels to templets for use in places where the cost of the steel is insignificant in comparison with the importance of getting a small percentage more service from the tools.

The utility and labor saving qualities of these bath hardening steels are being so well appreciated by the wide awake consumer that they are being made in round and other shapes, and are used for tools that it has been considered unsafe to use them for heretofore owing to ignorance of how to harden them safely. (See cut No. 14.) In fact, they have been found out to be superior to anything known for all cutting tools not liable to hard knocks or severe blows, or subject to speeds great enough to start their temper. In this latter case the self hardening steels stand alone—or, rather, it should be said that they stood alone for the last thirty years, for all high speed and roughing work.

The steel makers of to-day, however, have discovered that they can improve the cutting and staying qualities of these steels by various other processes of hardening treat-

Cut No. 14.
Two milling cutters made from a high alloy steel. Hardened by heating in a gas oven furnace.

ment not employed on the original self hardening steels, so that they bid fair to outstrip the bath hardened alloy steels that have only recently begun to be appreciated

by the general public. Yet up to the present time the bath hardened alloy steel stands supreme for such tools as threading tools, fine diamond points, finish boring tools and all tools used on the lathes, planers, slotters, shapers and turret machines where a fine cutting edge of exceptional wearing qualities is desired, and the tool is of such a shape that these steels can be safely used. (See cut No. 15.)

Many small pieces of steel are used in turret and screw machine work in combination to form cutters to cut special shapes. Most of these are made to templets, and the labor expended on them is many times the value of the steel employed, so much so that it is estimated that a very small percentage more of service more than pays for the highest priced steel. When one takes into consideration the increased production, the saving in labor of the tool maker and the operator of the machine, the avoidance of delays in frequently stopping the machine to make a change of tools, the lessened amount of spoilt stock and the superior finish of the work produced, this statement appears mild.

The writer knows of a case where a small manufacturer was producing large numbers of special shaped pieces from ⅝-inch diameter soft steel rods, and was finding fault because he could not get steel for his box cutters and cutting off tool that would remain sharp and cut clean for a half a day at a time. He expressed himself as being willing to pay any price for a steel that could do this, as the tools when they became dull scratched and tore the work so that it required a great amount of polishing to get the surface required for nickel plating. He was persuaded to try a certain alloy steel for these tools, with the understanding that the salesman should

Cut No. 15.

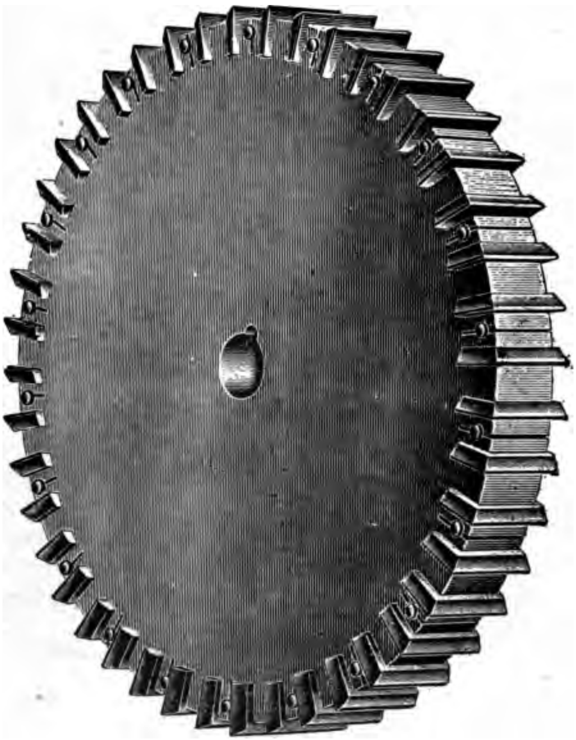
A set of tools used on light lathes for fine, light work or finishing. Are best when made of one of the hard alloy steels. No. 1, left-hand side tool; No. 2, right-hand side tool; No. 3, right-hand offset side tool; No. 4, right-hand diamond point; No. 5, left-hand diamond point; No. 6, round nosed tool; No. 7, cutting off tool; No. 8, straight threading tool; No. 9, offset threading tool; No. 10, grooving tool; No. 11, boring tool; No. 12, inside threading tool.

return when the steel came and harden the tools. If they did not stand half a day he should take the steel back, as it cost more than double what he had been paying.

The tools were made and hardened by the salesman, who then left, promising to call the next day for the verdict. The tools were put to work at 10.40 a.m. Wednesday morning, and the salesman called Thursday about 4 p.m. He found them still working O.K., to use the words of the manufacturer, who was so pleased that he gave the salesman a check for the bill of steel and another order for a quantity without any conditions attached, requesting him to call next week and show his man how to harden the cutters, which the salesman promised to do. The salesman called on the following Wednesday and found a highly pleased customer, who immediately took him out into the shop. There he found a happy screw machine hand, who had found his wages largely increased, as he was working piece work, and the cutter, started one week, three hours and thirty-five minutes before, was still working and turning out better work than was averaged with the old steel when first sharpened, so the manufacturer and his man stated.

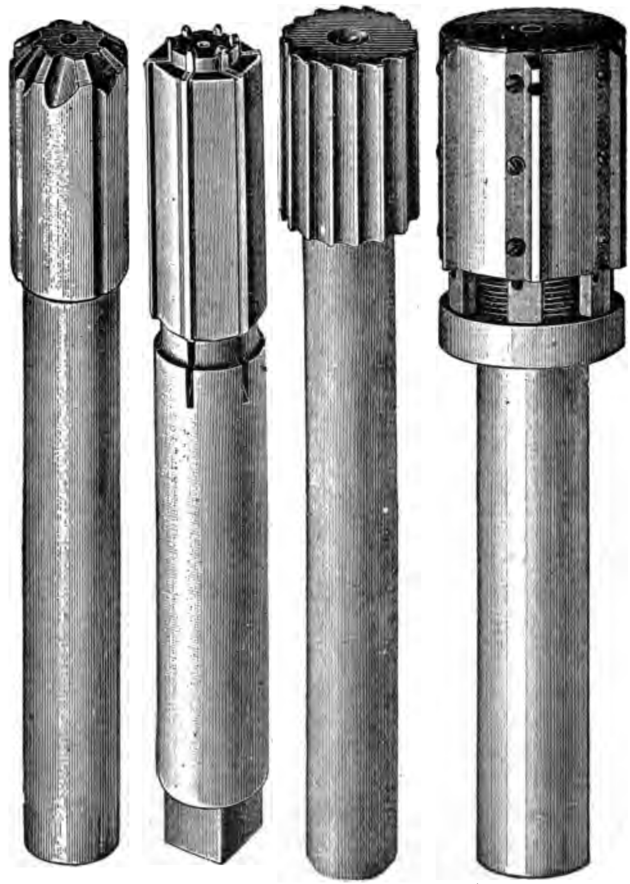
The above is not an exceptional case, but a mild one. It is perhaps above the average, because the stock used was just right, and the best quality of lard oil was used for a cutting lubricant. Suffice it to say that the above statement, which may seem strong to some, has been dwarfed by statements made by reputable mechanics about results obtained from still other steels which have appeared even to the writer himself like exaggerations of fact.

Bath hardening alloy steels are also used for many other tools to great advantage by the skillful mechanics, such as scrapers, inserted teeth in large reamers, milling cutters, etc. (See cut 16.) They have also found friends among the makers of hob taps, where the slightest possible change in hardening is desired, and an extra amount



Cut No. 16.

A large milling cutter with inserted teeth. Body of the cutter should be made of a good grade of common crucible steel; the inserted teeth should be made of one of the bath-hardening alloy steels.



Cut No. 17.

Four different styles of chucking reamers, two being solid and two adjustable with inserted teeth. The best material known for these inserted teeth is one of the high grade, water-hardening alloy steels. The stem and body for holding these teeth should be made of a cheap grade of crucible steel hard enough not to batter easily; the solid reamers should at least be made of an extra quality of tool steel, though they could be made of the alloy steel also with good economy.

of pains to achieve this object is given. Alloy steel can also be used to great advantage for inserted teeth (see cut 17) in rotary planers, broaches not of too complicated shape, with fine and shallow teeth, where fine finishing broaching with accuracy is particularly desired. Considerable call is being made for this alloy steel in round shapes for finish reamers, for gun work and other kinds of work. where the longest service possible is desired before the tool loses its shape by repeated honing. In chambering reamers for gun barrels it has been found superior to the expensive double refined steels costing fully as much, or more, and has a much longer life. It is also used with advantages for reamer drills used in boring gun barrels.

In buying this alloy steel for these above mentioned tools care should be exercised that it is placed in the hands of skilled tool makers, who are progressive and not biased in favor of some steel that they may have used ever since their apprenticeship days, and who have not grown old with the idea that no improvements can be made in the steel business.

This brings us down to the question of the utility of the various self hardening steels which have resulted from Mushet's discovery as well as the bath hardening steels mentioned above.

Very little, if any, improvement was made upon Mushet's production for thirty years following its discovery, though many were produced that compared favorably with it, each of which found its friends. It was not until the year 1898 that any noteworthy improvement was made either in the steel or the method of treating it, and when this improvement was made it was discovered that one of the steels in question, if submitted

to a peculiar treatment that was popularly supposed to ruin any steel, made tools that were far superior to anything ever made from any of the self hardening steels tried before.

The experiment was then tried on other self hardening steels (Mushet's included), and it was found that bars that had been condemned as being too soft and not hardening in the regular way when treated by this new process made better tools than those made from bars that were previously considered satisfactory. This gave the steel makers a clue that has resulted in the market being flooded with air hardening steels, with fancy names to distinguish them from the old self hardening, and still fancier prices to cover the expenses of selling them and the cost of exhaustive experiments still in progress to enable each maker to excel the other in the near future. The claims made for these new special treatment air hardening steels are of a nature that fill the old time mechanic with doubts, and the showings made with many of them fill him with wonder. Indeed, it is plainly apparent that we are on the eve of a complete revolution in shop practice that will necessitate the use of more powerful machinery and a complete change in the time honored methods. Attempts have been made to monopolize the various processes for treating these new steels, and various claims as to being the orginators of them have been made; but it is a singular coincidence that the man who made the accidental discovery never made any claim to it, and shortly afterward went into another branch of business never paying any more attention to the self hardening or air hardening steels or processes up to the time of his death some time afterward. One thing is apparent, and that is that the machine shop that desires

to keep abreast of the times and compete successfully with others must be equipped with this new steel for its heavy and roughing work.

Whether this steel will prove economical for finishing is still an open question which will be determined by the amount and quality of work that it does when put to the test. Heretofore the tool that has proved the best one for roughing has been found wanting when tried as a finishing tool, but we may be on the eve of learning something new.

One cannot attempt to state the limitations of a comparatively new discovery on which improvements may be expected every day and for which extravagant claims are being made from many quarters. But it is very evident that these new alloy steels have a much wider range of usefulness than the old self hardening steels. Whether, as claimed, they will supersede and replace the water hardening alloy steel is also a possibility which the writer is inclined to doubt. At any rate the price will have to be lowered and the elements of uncertainty and lack of uniformity be entirely eliminated before the high speed will take the place of the leading water hardening alloy and high grade carbon steels that have only recently taken root in the confidences of the progressive consumer. There is no doubt that some wonderful results are being obtained from these new high speed steels. The writer has seen reamers made successfully from them, for the severest kind of work, and seen them stand better than any other ever tested at a speed 40 per cent. higher than the others were used at.

In another shop where the tool maker had made a milling cutter for milling other cutters of ordinary tool steel, of which he makes quantities, he had the universal

milling machine speeded up so that the cutter was running at a surface speed of 170 feet per minute, and was milling an arbor full of 2½-inch diameter cutters. After completing the circle of teeth on the arbor full of cutters, making about 10 inches in length by 2½ inches diameter, the cutter was taken off and examined. (See small cutter shown in cut No. 18.) It showed no signs of getting dull, and he then took a hammer and said: "Look at this." Thereupon he struck one corner of one tooth a sharp blow without even chipping it, and remarked: "I guess that in this steel we have got what we have been looking for ever since I was a boy, something both hard and tough."

One of the drawbacks to the general use of this steel is that some of the alloys that enter into its composition are expensive, and in a measure comparatively rare, and the demand would soon outstrip the supply. This and the excessive prices charged will act to prevent its adoption for general use in all sorts of tools.

Notwithstanding the high prices secured for these new steels, in some cases ranging as high as $1.50 per pound, it is extremely doubtful if any of the manufacturers of them have realized much profit, owing to the expenses of selling and the fact that nearly every bar sold has had to be followed up by an instructor to show how to work it in order to get the best results. And then when they think they have secured a customer they are informed that some other maker has furnished a steel that beats theirs out of sight, and they have all the missionary work to do over again. At the time of writing it is impossible to predict where this spirit of rivalry will bring up, or what it will produce in the way of high speed and high priced alloy steels. One can only

Cut No. 18.

Large milling cutter made from a high alloy steel for severe service. Hardened in a gas oven furnace; temper drawn to 430 degrees in hot oil. Small cutter made from one of the new air hardening steels: heated white hot and cooled in lard oil; temper drawn to 400 degrees.

wait, and in the meantime take advantage of what improvements may be made as fast as they are proved to be a source of economy in shop practice. It is highly probable the next decade will bring forth many improvements in steel making that will be of benefit to the consumers in more ways than one. At any rate, the writer thinks so—and it is presumed the reader hopes so.

NOSTRUMS, NEW METHODS, PROCESSES, ETC.

CHAPTER IX.

The country is overrun with the man with the new receipt for saving you money in your tool account that will enable you to use a cheap steel in place of the expensive ones you may be using at present, or one that will make your tools do twice the work that they are now doing by simply dipping them in his compound when being hardened, or before hardening, or when partly forged, as the case may be. You are interested, of course, in anything that may promote the welfare of your firm to the extent claimed by the seller of the receipt. With the interests of your firm at heart you strike a bargain with him, and exchange a share of the firm's financial assets for the said receipt. When you open it and read the secret that has cost your firm several dollars you find one of the simple combinations of chemicals that have been known since the days of blister, shear and double shear steel, and perhaps many centuries before, and elaborate rules for applying the same with particular directions regarding the right heat to use in forging and hardening. In nine cases out of ten if you tear off the part of the receipt with the directions on about heating to forge and harden, and see that your smith follows them to the letter, you will have preserved all that is of value to you, providing you use a steel worth having around the shop.

The main point of merit about most of these receipts are the directions, because they will persuade the smith

to use the proper heats in forging and hardening, which he would not do if not following a receipt. If there is any particular fad or hobby that appeals to the average blacksmith more than any other, it is a fondness for receipts, hardening mixtures, etc. An incident that came under the writer's notice may not be out of place if related here.

The writer was calling on a machine building firm in a New England town when one of these receipt men put in an appearance. He had a receipt for sale for hardening steel and toughening it, so as to improve its natural wearing qualities at least 50 per cent. He had a box of the compound with him with which he was prepared to prove his statements if they would allow him to do so. Of course they agreed, and we all adjourned to the blacksmith's shop. After being introduced to the smith, he asked for a can of crude petroleum. Since this was used for fuel nearby, one of the firm told the apprentice boy to take a quart can from a pile in the corner of the shop (the firm manufactured machinery for making cans), and get it filled at their neighbor's. The boy soon returned with a can of crude oil. In the meantime the receipt man had been redressing a cold chisel, and, on the return of the boy, he opened his box of compound and took a small pinch of the material in it, and dropped it into the can of oil. He then removed the chisel from the fire and immersed it in the can of oil, allowing it to cool off entirely, or nearly so. He then reheated, hardened and tempered it in the regular way. The chisel was ground and put to severe tests, and stood them all remarkably well. While this was going on the writer had sent the boy with a duplicate empty can for another can of oil, with the consent of one of the proprietors. When

he returned we quietly substituted the can of plain oil for the one with the pinch of compound in it, and the partner who was in the plot asked the receipt vender to dress and harden another chisel. He did so, using the plain oil without suspicion, and produced the same result. For obvious reasons the proprietors did not purchase the receipt, but the blacksmith got so interested that he bought it on his own account when he found that the firm were not going to purchase.

Another kind of vender that makes great claims for his wares is the one with the hardening liquid, sold at a fancy price per gallon or by the barrel. There are the usual number of disinterested recommendations from customers whose blacksmiths got the benefit of the special directions about heating to forge and harden. Many of these are of no value at all to mechanics who thoroughly understand their business and who are provided with a reliable steel for their tools to start with. Some have virtues to recommend them in the shape of adding some help to the question of cooling quickly, when heated rightly, and heating properly in order that the prescribed routine may be strictly followed, more care being taken on these points than would be without the receipts or compounds. While it must be admitted that some of these nostrums may have some other virtues outside of their compelling qualities toward right treatment, it is the writer's belief that any shop equipped with good reliable steel for general purposes and the higher grades of alloy steels, both bath and air hardening, and competent mechanics to handle the same, can get along quite as successfully without them as with them; and, if needed in their opinion, find that their own man can compound them.

We also have a man who proposes (for a consideration) to show us how to turn scrap pieces of miscellaneous machinery steel and iron into high grade tools by a simple hokus pokus treatment. Also, a man who tells you that he can take your patterns made for any shaped tool or part, and get you castings at the price of malleable iron, which you can finish cheaply and turn over to him to be converted into tools that will make those made of high priced steel look like thirty cents. These pioneers of progress bob up at short intervals, and many find credulous clients to back them up financially. For a time they seem to flourish like a green bay tree, and then they fade away and nothing more is heard of them, but others follow in their footsteps rapidly and find new disciples, until one becomes convinced that there is considerable truth in the favorite saying of the sporting fraternity. It is probably necessary that these investigators be encouraged and patronized to a certain extent in order that their investigations may continue, and by some lucky chance the philosopher's stone be found. But they really stand about as much chance as the alchemists of old who tried to turn brass into gold with similar processes.

However, their investigations may possibly lead to good results in convincing others who have contemplated some such plan with the same intention and faith in its feasibility. Every mechanic has hobbies at some period of his career, until he becomes familiar with the insurmountable points in the field of investigation. Again, if we had no investigators we should have no progress, and often have men started after a wrong idea and returned with the right one, by becoming convinced of their mistake and devoting their energy to other channels that gave better promise of success. The writer does not wish

to be understood that none of these receipts, new methods and special processes are of any account, for there are probably hundreds that he knows nothing about. He only expresses the personal opinions formed after twenty-five years' experience spent in using and selling steel. If the ideas expressed in this paper seem biased it is because he has seen hundreds of these receipts, compounds and new methods tried, and up to the present time has failed to see one assist a manufacturer who was equipped with good steel and skilled workmen to work it. That the instructions that accompany them have been of benefit to many who were not treating their steel right without them cannot be denied, and, as a consequence, the credit has been given to the nostrum instead of blame being bestowed upon the steel worker for what he was doing with the steel before he tried the nostrum.

Regarding the new methods of converting cheap machinery steel and pieces of railroad rails into expensive and reliable tools that any well organized shop could afford to use very little reasoning on the part of the consumer will convince him that this is an impossibility. For instance, the element of variation in cheap steels is what makes them cheap and worthless for expensive or labor saving tools, and confines their use to places where this point is not so important. If these cheaper grades of steel could be made uniform and reliable the crucible steel industry would die within twenty-four hours after this result was achieved and generally known.

It can be easily understood that no specific rules of treatment could be applied to a steel lacking uniformity, one varying in composition with every ingot, every bar, and even on the opposite side of small pieces, sometimes.

Any good tool maker knows that it is this variation that proves fatal to economical results in tool making.

It is this desire for reliable and uniformly even steel that has made the consumer willing to pay fancy prices to get it, and it is the steel maker's knowledge of this desire that has led to much imposition on the part of some steel makers, who simply do not make reliable steel, to charge high prices for a quality of steel that a reliable maker would be willing to sell for less than half the price.

Again we repeat that to make good steel we require good iron and good workmen, and this combination costs high and makes cheap prices impossible. The reader will bear in mind that we are viewing this question of tool steel from the standpoint of shop economy, and do not deny that some remarkably good steel is made at low prices. In fact, the writer has no doubt that any of the leading makers can furnish a steel at a low price that would discount the much vaunted ancient Damascus steel. This much vaunted and primeval steel, that poets have sung about and historians written about, would bankrupt any machine shop in short order that attempted to use it for tools, and any maker of fine tools for the market would never get a second order on the merits of the tools furnished on the first one, if made from this steel.

No doubt exists that Damascus steel was far ahead of anything known at the time of its conception, and doubtless deserved all that was said about it, but if offered on the market at the present day it would bear about the same comparison to the high grade steels now made as the dugout bears to the steamship. It is said that the art of making Damascus steel is among the lost ones, but plenty of specimens are in existence for the

present generation to judge by, and when these specimens have been tested and compared with the product of to-day all the cherished ideas about it that have accumulated in our minds since boyhood have vanished, and we involuntarily felt thankful that it was numbered among the lost arts. Perhaps it may be cruel to become iconoclastic in regard to these time honored ideas that have been handed down to us, but it must be remembered that we are discussing this question from an economical standpoint, not a sentimental one, and all the rank humbugs cluster about the legendary lore of Damascus steel like flies around carrion. So it becomes necessary to expose the fallacy of the ideas that this steel was the eighth wonder of the world, which seems to be the impression that many people have.

DEFECTS IN STEEL, HOW PRODUCED AND DETECTED.

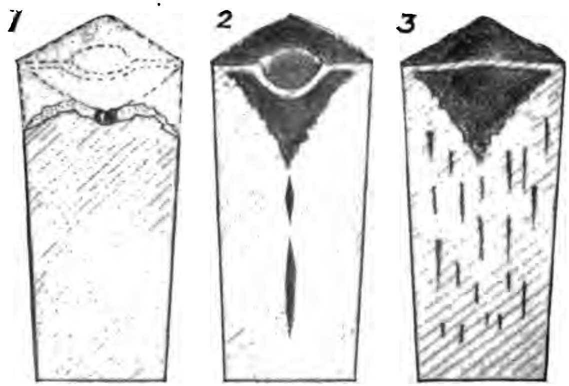
CHAPTER X.

One of the greatest sources of loss to the consumer, as well as one continual source of expense and trouble to the steel maker, are the various defects that are found in steel in spite of the utmost care on the part of the maker and user. This is also one of the causes of expense in making high grade tool steel, as well as one of the points that make low priced steels expensive to use from the extra amount usually found in them.

One of the worst defects, which is the hardest to detect, are interior seams or streaks, which contain enough foreign matter to burst the piece when it is hardened, no matter how large the piece may be. These streaks are the result of imperfect and careless melting of the steel when in the crucible, and show that the steel was not thoroughly killed before being pulled, or taken out of the melting furnace, either from carelessness on the part of the melter or from uneven and imperfect combustion, or deceiving conditions existing that mislead the melter. (See cut No. 19.)

Next in order we find closed up but not welded pipes that as a rule run through the center of the bars at intervals in some cases and in others extend the whole length of the bar. (See cut No. 20.) These also cause the steel to burst in the hardening process if not fully removed in making the tool. They are caused by the cooling of the ingot from the outside and the interior heat holding the

outer shell expanded until it becomes rigid. The continued cooling from all sides creates a sort of vacuum which in many cases is filled with molten steel from above. This carries down portions of the residue that have risen from the steel in melting, preventing the steel from uniting in the welding process, and changing the nature of the steel in its immediate vicinity, as well as its appearance, slightly.



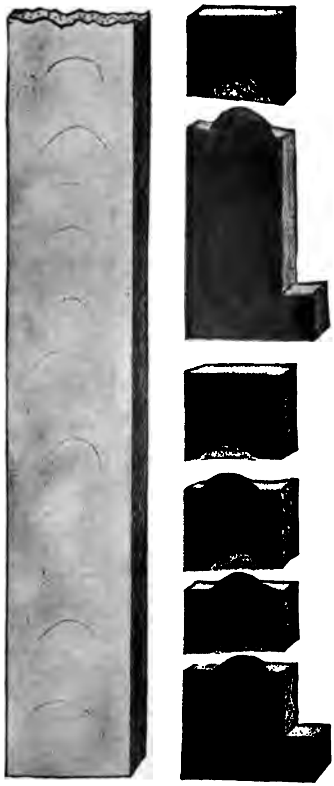
Cut No. 19.

Half sections of three ingots, one of sound steel topped, No. 2 showing a badly piped ingot, and No. 3 a streaked or improperly melted ingot. This last one is worthless for tool steel and No. 2 is nearly so.

Third on the list comes the deep surface seams that are too deep to be removed in machining the piece and which must be removed to avoid breakage in hardening. These are caused in several ways, and there is very little excuse for the maker who allows steel having them to get out of his mill. One of the causes of the worst of these seams are bubbles just under the surface, which become

Cut No. 20.

Two pieces of piped steel showing the line of the pipe through the center of each piece and the lines of the grain radiating from it. These pieces were broken in this shape by striking the outer diameter with a sledge, and show the natural structure of the steel as it left the rolls, without having been changed by heating or quenching.



.Cut No. 21.

Section of a bar of 1 x 3-16-inch high grade steel with the scale ground off to show the checks or laps caused by improper hammering at improper heats; also two cutters made from same bar, showing the way these cutters broke.

elongated just in the same proportion to the amount of space they occupy on the ingot. Others are from surface holes that are easily detected. Still others are from surface seams in the ingot, quite as easy to detect by the steel inspector. Others are caused by laps made by careless hammering of the bars and are better known as cold shuts; these sometimes start at the first blows on the ingot and become elongated as the ingot is drawn out into bars. (See cut No. 21.)

A large portion of these defects may be detected by the consumer in a very simple and easy way before he has expended much in expensive labor on the steel. The best and surest way to detect them is to cut the pieces required by the ordinary power hack saws, cold, without the use of oil or any other matter that might soil the newly cut surface. When the piece is properly cut with a sharp saw the cut surface will present a perfectly uniform appearance, like satin finished silver, if the steel is sound. If piped, a slight change in the center of the bar will be noticed, if the pipe is closed up. If the pipe is a bad one it will be well defined by a hole or dark spot, with faint appearing arms radiating toward the outer circumference of the bar.

Pieces with interior seams will show faint specks of a different shade from the sound steel. (See No. 3 in cut No. 22, also cut No. 23.) The deep surface seams can also be detected in the same way, and the chances are that if the steel is cut into reasonably short pieces, as are required for the majority of tools, and both ends of the piece carefully examined while the cut is fresh and free from blurs on the new surface of the cut from handling, these danger spots can be detected and the piece discarded before more work has been expended on it.

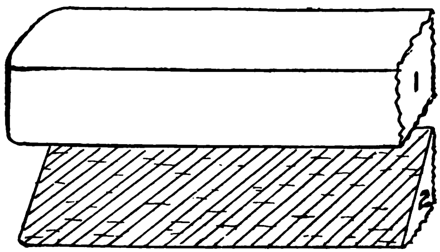
The above comprise the list of the common defects most frequently found and which make the most trouble for the consumer. The piped steel is the only one of these for which the steel maker cannot always be blamed, and he is not exempt from all blame in the rank cases of this defect.

Cut No. 22.

Three die blocks made from three different specimens of steel as shown in the three ingots in Cut No. 19. No. 1, sound steel; Nos. 2 and 3, unsound steel. The spot shown in the center of No. 2 is a closed up pipe. The numerous spots shown in the end of No. 3 indicate streaks of foreign matter. Both of these are shown more plainly than they would show in a piece of steel. A slightly brighter spot than the rest of the steel, with sometimes a dark speck in the center, is about all that usually shows on the most dangerous pieces.

A steel maker demanding and receiving a good price for his product should be expected to have men competent to see that no badly defective steel leaves the mill. Pipes that are small and always occurring in the center of the bar and sometimes remote from the ends will occasionally escape the most rigid inspection, but not often.

There are several other defects that the steel consumer must guard against, especially if he is using a low or medium price steel, from a maker of doubtful reputation. Among these may be mentioned over melted steel, that was not withdrawn and poured when sufficiently melted, but allowed to stay at a high heat after it was killed. Another is overheated steel that was melted at too high a heat. This latter is rare among makers of reputation. Hot short and cold short are other defects found in cheap



Cut No. 23.

This cut shows a billet made from No. 3 ingot shown in Cut No. 19, also shows it sawn through diagonally from end to end, plainly showing the streaks of oxide that would burst any tool made from it in hardening.

steel (and steel should be sold cheap indeed that shows these points of weakness), caused bv foreign matter and careless mixing and working all through. (See cut No. 23.) The terms are descriptive of the way they work, hot short becoming brittle and crumbly under the hammer in forging, and cold short being brittle and short when cold, though forging all right. These last mentioned defects sometimes appear in steel made from high grade material, but in this case denote gross carelessness on the part of the maker. More often they are found in steel made of cheap iron of so ununiform a nature that the

best workman in the world is not sure of his work, as the basis to work by is lacking. Steel having these defects should never be made into expensive tools of any sort, as it is money wasted.

Overheated and overmelted steels can be best detected by their lack of wearing quality in cutting tools. Hot and cold short steels are readily detected by forging. The former shows its weakness at once, and the latter when made into a tool and tested for strength.

Decarbonized steel is another defect that results from carelessness in making and from improper annealing. Bars have been produced that were decarbonized on one side and were all right on the other, but these are rare.

Over annealed steel is another form that sometimes escapes from the mill inspector, and this is partly due to the demand of the consumer for steel annealed so soft that he can work it like soft machinery steel.

When we include the ununiform steel, varying in temper so that the man who hardens tools made from it is never sure of his ground, we have enumerated about all the defects that we can blame the maker for, and this brings us to the defects made by the workmen that work the steel after it reaches the consumer.

Prominent among these we have the bursted center of round pieces, produced by improper forging, as described in the chapter on forging. Then we have the strains, also described. The air burns will be further mentioned in remarks about hardening.

STEEL FOR MISCELLANEOUS TOOLS AND PARTS.

CHAPTER XI.

There are many places where various grades of tool steel can be used to advantage that have not been mentioned. To enumerate them all would prolong this work to a greater extent than is feasible, but it may not be out of place to mention a few of them for the benefit of those who have never come in contact with these requirements, but are liable to do so at any time.

One of the tools that mechanics think can be made of almost anything in the shape of steel is the drift pin in boiler shops. It is of the utmost importance that these tools be reasonably hard on the outside, and at the same time be extremely tough so as to withstand the side blows given them in use. Any of the leading makers can furnish a steel at the lowest price of crucible tool steel which fills these requirements fairly, if they are advised with the order what the steel is to be used for. The best and most serviceable, and consequently the most economical, steel to use for these pins is the soft centered steel, made with a tool steel on the outside to harden, and a tough grade of mild steel in the center that will not harden, which should be about one-half the diameter of the pins. If this sort of a steel is used the boiler maker will find that his supply of pins will last many times longer, that the men will be able to do better work with them and also very few men will get hurt from broken pieces flying during the drifting process.

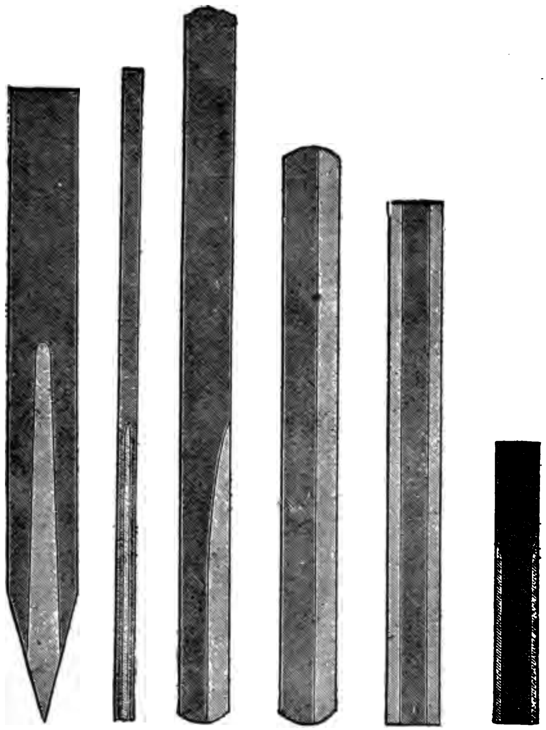
Another place where considerable discrimination can be used is in the grade selected for welding on to iron or mild steel, as the case may be. For instance, should you be manufacturing rag knives or barking knives, used by the wood pulp manufacturers, or should you be manufacturing knives for lawn mowers, or any other sort of knives where the requirements do not demand the best steel and competition will not permit of its use, the grades of best tool steel (best cast steel) made by the leading makers, will be found to give quite satisfactory results. Should you be making planer knives, paper knives, knaping knives and many other knives where the best possible wearing, keen edge is desired, a steel costing at least 12 cents per pound will be found the most economical and satisfactory to your customers. Steel is welded to iron and low grade steel in many shapes.

The cut No. 24 shows some of them, and cut No. 25 shows some shapes used for shoe dies and other dies which require a continuous edge made by welding the ends together.

For parts of machinery, such as crank pins of engines, hardened studs and many other parts requiring a hard surface combined with all the strength possible to obtain, which is best obtained by case hardening in mild steel, especially made low carbon crucible steel will be found the best. By using this material, made by a reliable steel maker with the proper understanding of the requirements, you secure a working part free from seams so objectionable in case hardened iron—a hard wearing surface combined with the strength and rigidity.

For high speed shafts, such as are used in wood working machinery, high class grinding and polishing machinery, and in any place where the best possible wearing

qualities combined with strength are desired, crucible machinery steel made especially for the purpose by any of the leading makers will be found far superior to any



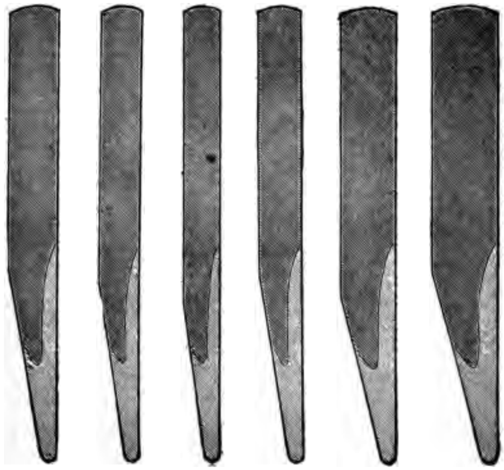
Cut No. 24.

Some samples of steel and iron welded together for various uses, the light part representing the steel and the dark the iron.

other kinds of steel. This crucible machinery steel, if properly made, should fill these requirements as well as the highest priced tool steel. However, you cannot ex-

pect to get a reliable crucible machinery steel for less than five cents per pound, and it cannot be made and sold for less if due care is taken all through the processes of making it.

For pickaxes and mattocks for pointing crowbars, ice breakers and the one hundred and one other tools where a certain amount of hardness combined with tough-



Cut No. 25.

Sample shapes of steel and iron welded together for making shoe dies, envelope dies and formed dies of various descriptions, where it is often necessary that the ends of pieces be welded together to produce required shape.

ness is desired, a steel should be purchased at about seven cents per pound that ought to fill all the requirements as well as the most expensive in the hands of a good blacksmith. For dredger pins, for clay and ore crushing plates, for stamps and shoes for crushing quartz, manga-

nese steel castings and forgings have almost superseded the use of crucible steel.

For the roughing tools used in the granite quarries and yards, such as splitting drills, steam drills, large points, sets and breakers, also shims and wedges, nothing is usually gained by using anything better than one of the leading brands of seven-cent steel.

For the finishing tools, such as lettering chisels, small points and smoothing chisels for bush hammer blades, it pays to use the better grade, providing you are fortunate enough to have a good blacksmith.

For augers, bits, for forks, shovels, hoes and garden rakes and many other tools that are not required very hard, but where toughness and elasticity are the main objects, good crucible steel should be used, costing about the same as crucible machinery, if made in quantities, for all parts subjected to certain and continuous shocks which subject them to incessant vibration, it will be found best to substitute one of the best grades of refined iron obtainable and case harden it after finishing to required size, or to the grinding size as the case may require.

The breakage in machinery of parts subjected to continuous shocks has led to lots of trouble and delays, many of which could have been avoided by substituting a piece of case hardened, high grade refined iron for the steel used in the troublesome part. Among these parts liable to breakage from constant vibration are stay bolts, crank pins, links, piston rods and rarely the side rods and axles of locomotives, cap screws for holding the bonnet on water wheel pits, driving cams and parts of high speed machinery subjected to constant blows, short suspender trusses in the center of suspension bridges, bolts in the

parts of structural iron bridges mostly subjected to the terminating point of vibration.

Several fatal railroad disasters are traceable to the use of steel in places subject to continuous vibration.

If you are troubled with some part of your machine constantly breaking down try a piece of high grade refined iron, case hardened, for the troublesome part, and make a note of the results obtained. Should you be manufacturing fine machinery in which there is a large number of wearing parts that are hardened hard, and for which you use considerable quantities of steel, you should expect to get a steel for about seven cents per pound that would fill all requirements as well as a higher priced one, especially if you bought it of one of the leading makers who understood the use it was to be put to. It is quite possible that in some of these parts you would find it policy to substitute case hardened refined iron, as mentioned above. Should you be manufacturing tools for the market on which their reputation did not depend on a fine cutting edge, you should be able to produce as good as any made from a steel purchased at about seven cents.

Part Second.

POINTS ABOUT

WORKING STEEL

INCLUDING SOME INSTRUCTIONS ABOUT WAYS
TO DETECT IMPERFECT STEEL

AND

SOME EXPLANATIONS OF WHY GOOD STEEL FAILS
AT TIMES AND ACTS IN A WAY THAT IS
MYSTIFYING TO THE TOOL MAKER

ALSO

CONTAINING SOME GENERAL DIRECTIONS REGARD-
ING WAYS TO HARDEN AND TEMPER STEEL,
WITH APPLIANCES WITHIN THE
REACH OF ALL.

The writer wishes to acknowledge his indebtedness for the many favors extended by

FREDERICK SEARLE, Supt. of Loring Coes & Co., Worcester, Mass., and

JULIUS ERLANDSEN, No. 172 Centre Street, New York City.

In justice to these gentlemen it is due to say that they must not be held responsible for the views expressed herein, some of which they perhaps would not endorse; but, as they are two of the best steel workers on fine tools that it has been the writer's fortune to meet, the writer values highly many items of information confirmatory of the ideas expressed herein as well as many courtesies extended.

G. W. ALLING,

New York City.

HOW TO TEST THE QUALITY AND UNIFORMITY OF STEEL.

CHAPTER I.

The consumer of tool steel usually buys steel for its working and wearing qualities, and progressive manufacturers and their mechanics generally understand that the best is the cheapest in the end. It then becomes an object to find out which is the best for their continued use.

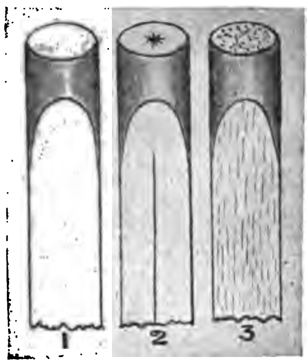
The main points are: The amount of work that can be accomplished with each tool made from a given steel before it becomes worn out, the amount of time saved and the amount of work done before each sharpening or grinding or forging, as the case may be. A most vital point in tool steel is to have it uniform and reliable in each lot ordered, especially if it is to be made into expensive tools that cost many times in labor, for each one, what the steel costs to make it from. (See cut No. 26.)

To determine these points as far as possible, it is a good way to take a test piece from each lot received, and compare it with the test piece taken from the preceding lot by trying in the same way. It is also a good plan to keep these test pieces for comparison as long a time as you may be using the steel in question.

The appearance of the pieces may be preserved indefinitely by the very simple process of wrapping them in clean, dry paper, and immersing the package in common powdered lime. A box of this lime, of small dimensions, will serve as a safe depository for the sample pieces that accumulate for some time, and if the date of each test is

put on the paper inclosing each piece the customer will be able to see whether the steel he is getting for a certain use is improving or deteriorating in quality.

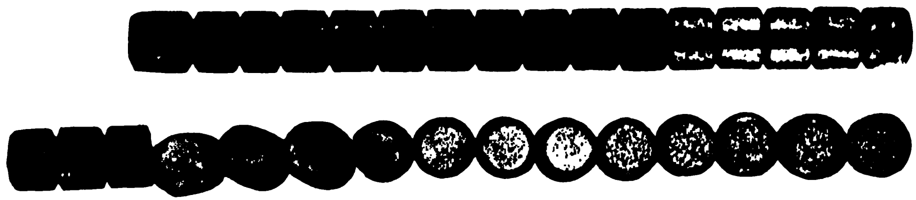
These test pieces can be made in several ways, according to the size of the bar being tested. For instance, suppose that the steel is a round, square or octagon shape, three-eighths of an inch or below in diameter. We take



Cut No. 26.

This cut shows three pieces of round steel slabbed off with a milling cutter to show the interior structure, No. 1 being sound steel, No. 2 a piece of a badly piped bar, and No. 3 a worthless piece of improperly melted steel.

two pieces about four inches in length, and mark them deeply with a file every quarter inch or less, and wire them together so that their ends will be even, and if square, flat or octagon, we twist the wire between them so that the heat may have free access to all sides. We then heat one end carefully in such a position that the lower ends will become red hot before the heat shows up more than one inch on the pieces. When this is accomplished we continue heating the end, watching to see that



Cut No. 27.

Test piece shown after being hardened, also after being broken. Note the difference in grain in pieces from right to left, also the end of the unbroken piece heated almost to the melting point.

our heat does not get toward the other end too fast, but that we have a nice tapering heat running from a melting heat on the end, down to a black heat about half an inch from the other end. If proper care is taken in securing this taper heat we have all the heats possible to use in hardening and refining steel of any temper. After this heat is secured we immerse the pieces in the bath, which is to be used to harden the tools to be made from this particular steel. After the pieces are thoroughly cool we wipe them dry and take one of them and break off a piece at a time, beginning at the end heated most, and breaking at the nicks or marks made with the file before hardening, laying each piece down in regular order as broken. (See cut No. 27.)

Of course, we shall find that the overheated end breaks easily, and, when broken, shows a coarse grain, common to overheated steel. As we continue to break off these pieces we find that the grain gets finer, and at a certain point is as fine as satin on one side, with a wrinkled or torn appearance on the other side. It is also noticed that it requires a much harder blow, and sometimes several to break this piece, indicating increased strength over all the preceding ones. If we break off the pieces above this one we shall find that the grain begins to get coarser after the first or second one broken above the one that shows the best fracture. It will be noted that the piece continues to resist the breaking strain, and at the same time shows an inclination to bend; when this occurs we have arrived at a point not affected by the heat or reached the natural grain, and there is no need of testing further.

Should the size on which the proposed test is to be made be larger than the dimensions mentioned above, and up to two inches in diameter proceed in this way: Place

the piece in the jaws of a milling machine in such a position that the saw of the machine will cut three-quarters through at one end and only one-quarter through at the other. in sawing it laterally. After sawing the piece lengthwise to the extent described, or nearly so, remove the square toothed saw and substitute a round edged one, and mill out enough to make the bottom of the groove concave, taking out the sharp corners left by the first saw. If a milling machine is not available, this can be done on a planer or shaper provided with a chuck having parallel jaws. A V pointed tool will also answer as well as the round edged saw, or a round edged ward file (for the want of a better tool) to cut out the bottom as desired. (See Cut No. 28.) After this is accomplished, heat the two pieces as near alike as possible, in the same manner as the others were heated, making sure that the overheating is done on the end least penetrated with the saw. Proceed with the hardening in the same manner. Wipe perfectly dry, and split one of the pieces lengthwise by inserting a wedge in the groove that will bear the whole length (this last is important) and force it in by pressure available. When the piece splits it will be found that the part sawed three-quarters through will show more strength by considerable than the end that is only sawed into one-quarter the diameter, but badly overheated in securing the desired temper heat. (See cut No. 29.)

By examining the fracture so produced lengthwise the piece, the full effect of the varying heat can be observed, and one section of the piece is bound to show the steel refined at its best. If the steel is a desirable one for expensive tools, the grain will be fine as satin, and wrinkles denoting strength radiate from one side at the point

Cut No. 28.

Test piece of a larger size than former one shown, grooved lengthwise to a depth of one-third its diameter at one end and two-thirds its diameter at the other.

Cut No. 29.

Same piece as shown in Cut No. —, heated at a tapering heat from melting on the end to a black heat at the other end, quenched, dried and split open. Note the coarse appearance at the burnt end, also the grain of the natural annealed steel at the other end and the proper refining grain about 1½ inches from this last mentioned end.

where the heat was right. If the operator has been observant enough to note the shade of heat that prevailed at the point where the grain is the finest, he will have the proper heat in his mind at which tools made from this particular steel should be hardened to be at their best.

For testing pieces from bars too large to treat in this manner, it is best to proceed in this manner: Cut thin disks from the end of the bar about one-quarter inch thick or less. If this is done with a power saw without a lubricant, the disk can be examined for interior defects before proceeding further. After this examination saw or cut the disk into pieces by cutting it through its greatest diameter into two pieces, then cut a piece from the widest part of each piece as near alike as possible, and proceed as in the first instance, or heat the disk itself while whole at a tapering heat if not particular. The remaining segments can also be used for testing at various tempers and in other baths, and thus carry the investigation further, if desired.

In making these tests it is well to take two pieces from the same bar and the same section of the bar, so that in case the first one tried does not prove as good as desired it can be confirmed by the other one. Again, should the one broken prove perfectly satisfactory, the other can be preserved intact, to be broken and compared later with another piece supposed to be the same steel.

To carry this test forward with all possible justice to yourself and the steel, care should be taken to heat the pieces exactly alike, and where practicable, to wire them together, as mentioned in the first example. It will be seen that if the man who does the hardening is duly careful to note just how the different shades of the heat are located and can reproduce the same heat, as shown, at the

point where the grain shows the finest and strongest, he has a good guide to go by in hardening the tools made from this steel. When a subsequent test is made for comparison, it will not do to expect that the newly hardened piece should require as much force to break it as the piece of the same size and kind reserved from the former test, as the latter has probably become toughened to some extent by resting, but the grain should appear about the same in fineness, and like the pieces preserved from the one broken in the previous tests. Some remarks on this point of resting steel will be found in another chapter.

It will be observed that these tests are simple and comparatively inexpensive, and that no special apparatus is required not found in any shop where the steel is made into such tools on which the cost of labor is great in comparison with the cost of the steel. Of course, chemical tests can be made that will show any variation in the various lots received, but unless this is done with the utmost care and in the most thorough manner it will not tell the tale as satisfactorily as the simple method described above. An analysis may show exactly the same carbon in three specimens, and yet one of them be worthless, another medium and the third excellent, but the simple tests described above will not mislead you if care be taken in the heating to get a perfect taper heat. In making these tests it is well to observe all the points as you proceed: the way the steel cuts, how it files, and whether it shows hard specks, streaks, stars, seams, etc. Smiths are familiar with the numerous other ways of testing steel. It is surprising that they have not tried this simple way to a larger extent. This method is also a good one for testing steel that is to be forged into tools, to ascertain how it works after forging. A piece can be forged to the de-

Cut No. 30.

Another shape of test piece. Piece of high carbon steel bent in shape of letter U and hardened with one end at the right heat and the other end greatly overheated.

Cut No. 31.

Another test piece. Piece of medium tempered special cast steel, bent in shape of horseshoe and heated to the right heat at one end and overheated at the other, hardened and broken to show the difference in grain between the right heat and the improper heat.

sired size from almost any sized bar, and marked as described and tested, but the uniformity should not be expected that should be found in pieces taken from the bars and tested with no forging. (See cut No. 30.) This way of testing a forged piece will be found of service to the smith in determining the right heat at which the steel in question should be forged and hardened, and is particularly valuable in this respect when trying a new steel which may require different treatment from the steel formerly used. After the pieces are forged to the desired shape they should be reheated and thrust into the annealing box to cool slowly, then they should be marked deeply with a file every quarter inch or so to assist the smith in noting the heat at various points, and enable him to break it easier. This marking or nicking should never be done with a cold chisel, as it changes the structure of the steel at the point where the judgment is to be formed. Use a file or saw in nicking the piece. One side will do, but if it is preferred, and the piece is round, it can be done in a chuck with a V shaped tool, or in case of flat or square shapes on a planer. Another way of making test pieces is shown in cuts No. 31.

FORGING STEEL.

CHAPTER II.

One of the most important points about working steel is to see that it is forged properly and without injury to its working quality. The urgency for such care varies according to the grade and temper of the steel being forged, and in each grade according to the use that the steel is intended for. For instance, a steel that would prove the most economical for lathe, planer and kindred tools requires more care in heating than that for chisels, sets, etc., because it is higher in temper and more susceptible to strains which develop into cracks when the steel is hardened after forging. The grain also is injured so that the steel becomes brittle, and the tool fails to hold its edge as it should if due pains were taken in the forging.

To get the best results from high carbon and high alloy steels, such as are found best for lathe, planer, slotter and similar tools, they must be thoroughly heated in a manner that will render the piece to be forged perfectly ductile from outside to center. This must be done. Care must also be taken that the air blast of the fire does not come in contact with the steel after it becomes heated to a low red heat, otherwise the steel will lose a large part of its cutting qualities. This danger is easily avoided by making sure that the fuel has not burnt out from under the piece enough to allow the air from the tuyere to strike it. Care must also be used in forging at the right heat from start to finish, and that the blows are not given too hard, or with too heavy a sledge in the hands of a strong

helper. High carbon steel has its limitations as to the rate at which the molecules can be moved in shaping the piece without losing their relation to each other, and if the steel is forced into the shape too fast in the forging the structure of the grain becomes changed and dry or short, making the tool brittle and incapable of holding a durable cutting edge. To avoid this result use judgment in administering the blows according to the amount of resistance met with. Thus the same blow that would be right for a piece of inch square steel would ruin a piece of half inch square. It is also of importance that the hammering is not continued after the steel cools below its point of ductility.

Large tools should be reheated several times in the forging process, according to their size, in order to achieve the best results. The idea that they can be refined and improved by hammering at a low heat is erroneous and a relic of the old blister steel days. On the contrary, after the tool is shaped it should be slightly heated above the point that it was at when the last forging was done, and the tool immersed in dry ashes to cool off slowly before it is filed up to shape desired before hardening. This filing up, of course, is not necessary in many tools used in shops where grindstones are cheap and plentiful, but if the tool is properly hardened it will be found that the less grinding the workman has to do on it the less time he will waste in the operation, and the snags, left by trimming the tool while hot, will not be in evidence to tear grooves in the face of the stone, which often prove a source of profanity to those who have to use it afterward, and often necessitate the turning off of the stone. This can all be saved by a few moments spent in filing up the tool to a point so that very little grinding is required to bring it to an edge.

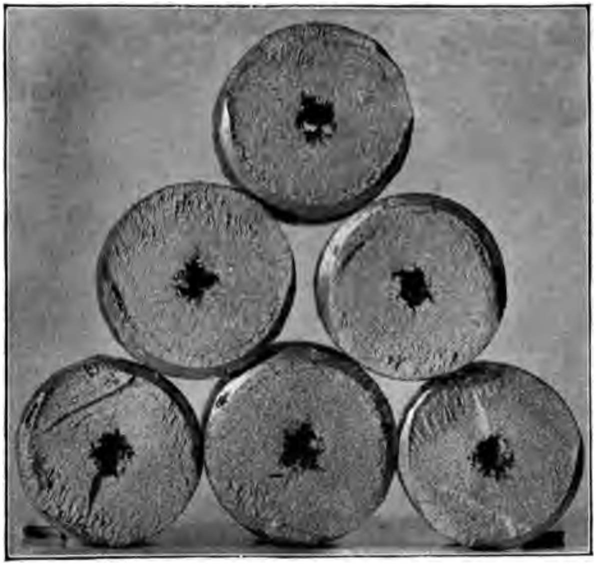
If the blacksmiths will pursue this course of reheating to remove any chance of forging strains, and allow the tool to cool slowly so that it can be filed (or rough ground) near the desired shape, and then take the utmost pains to harden the part to be used, and not overheat the extreme edge in getting the larger part hot enough, they will lessen their own work considerably, as well as saving steel bills, time spent in the grinding, time wasted in stoppage of machines and rapid wear of grindstones, etc., providing, of course, the other part of the work is done with the same care, and the firm furnishes a steel that is worthy of the treatment and care required by any steel that it is economical for a well regulated shop to use.

If it should chance that you are running the shop for amusement, and with no regard to the profits, or an asylum for antiquated notions and prejudice, you can afford to ignore the above points, but not otherwise.

The foregoing applies to high carbon and high alloy steels used where the best and most economical results are desired, but this treatment may be applied to any grade of steel with a less amount of advantage—that is, any steel of high enough temper to be made into any kind of a cutting tool that is susceptible of being hardened. It is not so important in the case of mild steels for heavy chisels, sets, etc.

The above suggestions may also be applied to forgings made of steel for parts of machinery that are to be hardened, and in this case will save the cracking of many pieces, and the warping out of shape of others after considerable labor has been expended on them, when the piece is hardened.

In forging pieces with several sizes terminating at a shoulder, some smiths make the mistake after heating the



Cut No. 32.

Six pieces of steel showing bursted center, taken from the same bar as shown in Cuts Nos. 33 and 34 : centers bursted by improper forging.

Cut No. 33.

Pieces of 2-inch bar of sound steel broken by cutting groove around it and then using a set, before forging to size shown in Cuts 32 and 34. See Cuts Nos. 32 and 34.

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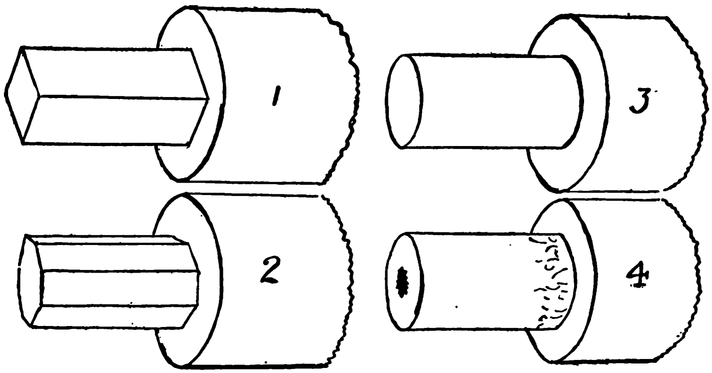
piece properly of then reducing it from the point of the shoulder to the required size too quickly, especially in round shapes, by rolling it under the blows of a hammer and rounding it up as they go along. (See cut No. 32.) This will spoil any steel as far as making a solid, strong piece that can be safely hardened without loss by bursting. (See cut No. 33.)

In order to reduce a piece of round steel to a piece with a series of sizes smaller than the original size, and therefore terminating at shoulders or steps, take a piece long enough to draw out into the required sizes without waste; mark the point where the first drop or shoulder is wanted, reduce the piece from that point to the size required by hammering it square instead of round, as far forward as you have the proper heat. After you have reduced it to the size required in a square shape, reheat, being sure that the heat extends above the shoulder. Then from the line of the shoulder make the reduced size octagon of still the same measurements as the square, as far down as the heat extends, hammering lightly, with only sufficient force to drive the four corners down to a perfect octagon. Reheat and serve the eight corners as you did the four, using still lighter blows for the purpose. You now have a piece with sixteen sides to it. It may now be rolled under light blows of the hammer, and rounded up with safety, if no swedges of the desired size are available.

You have a piece that is as solid in the center as when started. Proceed in the same manner from the next desired shoulder for the next smaller size, and so on. (See cut No. 34.) If the piece is rolled under the hammer in drawing down to the required size in round shapes from the start unsound forgings will be made, with burst

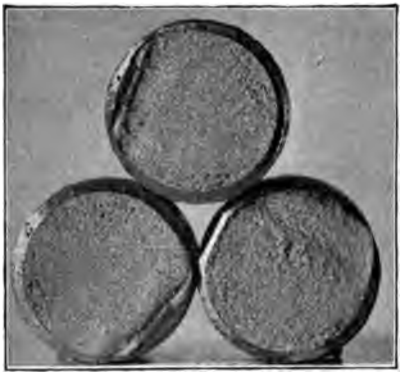
centers or weak, spongy cores. It will also be likely to have laps and cold shuts on the outside that may extend too deep for finishing off. (See No. 4 in cut No. 35.) This point of bursting steel in the center is not confined to high grade steel. It occurs in mild steels and even in iron, when improper methods are used in reducing or drawing it down. (See cut No. 35.)



Cut No. 35.

Four drawings showing the right and wrong way of reducing a large diameter to a smaller one. Nos. 1, 2, 3 show the proper forging operations required to produce sound steel rolls or other forgings having several varying diameters, No. 4 shows a forging that has been brought down from the larger diameter by rolling it under the hammer and forging it round from the start. Note the bursted center and the cold shuts at the shoulder which did not clean in turning up the piece.

Another favorite way with smiths to spoil good tool steel is to have forms made in dies doweled together for the various tools and shapes that they have a continuous call for. They pride themselves on the fact that they are able to make a smoother forging by this method than by hand hammering, and that the helper has to exert most of the strength required to produce the work. These shap-



Cut No. 34.

Three pieces broken from same bar as shown in Cut No. 33 after being reduced to one-half the former diameter by proper forging.

ing dies are all right if they are used right, and become a valuable asset in any well equipped shop, but if they are not used right they should be dispensed with entirely, as much mischief can be done with them by smiths who try to make them do the entire job. The writer has seen a smith take a piece of high grade steel and heat it with a quick surface heat; withdraw it from the fire and hit it two blows to batter the corners and remove the fire scale, and then open the dies and insert it between them, and have the helper pound the top die until it refuses to budge further, pound it with a vim of a farmer driving a stake in a contest at a county fair, where the prize is a yoke of oxen for the man that drives it deepest into the ground with a certain number of blows.

After the smith mentioned has finished the tool, he hardens it in his regular way, and as he immerses it in the quenching bath he hears a snap, and feels a kick in the hand that holds the tongs. When he withdraws the tool he finds that he has left a piece off the point of it in the bath, and, on close inspection, finds several more cracks. He then pronounces that particular steel seamy, rotten or no good, and immediately discants on the virtues of some cheap, mild steel that bears no comparison in working and wearing qualities with the steel which he has just spoilt. The above mentioned shaping dies are for assisting in hand forging, and should only be used to finish pieces of hard steel after they have been forged as near the shape as possible, consistent with reason and the shape of the piece being made, otherwise they will work to the disadvantage of the user.

In forging parts that have a thin edge and a thick section, which must be shaped at the same time, care should be used that the thin part does not lose the required heat

to make it ductile during the operation of drawing and shaping under the hammer. If this care is not used it will be found that small semicircular checks will be in evidence when the piece is hardened, which weaken the steel and make starting points for more serious cracks when a strain is put on the piece in work. This particularly applies to high grade steel having the best working qualities for tools, such as axes, framing chisels, ice breakers, cold chisels, etc., where the best possible steel for the purpose is furnished by the steel maker, under the assumption that the user understands how it should be treated.

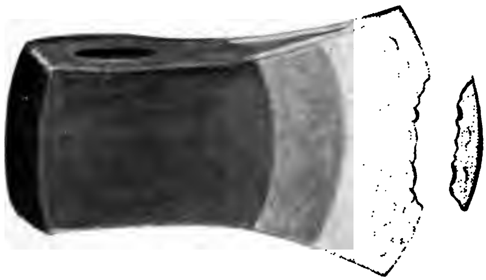
It will not be amiss to cite an illustration that fell under the observation of the writer: A certain maker of axes and kindred tools, who prided himself upon the class of work that he did and the price that he was able to command for his product, was persuaded by a steel salesman to try a couple of tons of a steel at a price little more than half of what he was paying for an ancient steel he was using, which was the kind his father used before him. It was the same quality as it had been for the last half century, a good steel, a reliable steel, which gave satisfaction to the buyers of the tools up to a certain point, but one that could be easily beaten by several cheaper steels properly worked. The salesman made such strong claims, however, that he was persuaded to try the quantity mentioned above, under the condition that he had the privilege of trying enough for one axe off each bar before he gave his verdict, to see if the steel was uniform, asserting at the same time that he was capable of working any steel so as to get the best results from it. The steel was shipped and received, and the axe maker proceeded to take enough for one axe from each bar, and weld it into the pole of the

axe and shape the bit to the desired shape. Sixty axes were welded up from the new steel, and the boss expert proceeded to hand hammer them, as was his custom with the old steel. After this operation had been completed he proceeded to harden and temper them, and afterward as a final operation he subjected them to the hammer test, which consists of laying them on an iron block and hitting them a smart blow with a hand hammer just back of the edge, not hard enough to break sound steel, but hard enough to break the edge if any flaws existed. In this test every axe of the sixty broke near the edge, at slightly varying distances. Some broke off half way round the edge, others a quarter way, and some all the way round. All were spoilt and worthless when the test was completed.

A mad customer dictated a strong letter to the maker of the steel in which he paid the salesman some compliments of a doubtful nature, and requested advice as to where he should ship the steel, as he had no use for such worthless stuff. The letter in question was sent to the salesman with instructions to straighten out the matter, if possible, but in a way satisfactory to the customer. He was not enthusiastically received, but was shown the broken axes with the broken surfaces, showing numerous small semicircular checks, all having their convex side toward the edge of the axe, all these showing black. From these small checks ran other cracks that showed a slightly rusty inside surface and some traces of salt from the bath in which the axes were hardened. From these latter were clean, new fractures made by breaking off the piece partly cracked off.

The salesman told the manufacturer that he was wrong in his assertion that the bars of steel were full of

flaws, and insisted that the axe maker who welded and forged the bits was alone responsible for them, and offered to prove it by making as many more from the same bars. On his agreeing to forfeit ten dollars for every one found with a flaw made under his supervision, and with the understanding that he was to burn the steel off the spoilt poles and use them over, he was permitted to prove his statement. When ready for welding on the bit he took hold himself and welded up and forged into shape twenty of the axes with the regular man looking on, who remarked that he would be discharged if he forged any bits at as high a heat as was used by the salesman. Then the regular welder took hold, with the instructions to follow the directions of the salesman, as the salesman was not dressed for the work, and had burnt a new suit of clothes badly, nearly ruining them. The twenty-first axe was withdrawn from the fire and partly welded and forged before the salesman observed that it was at a heat below what it should have been. The salesman marked this axe No. 21 on the head, and stood by to direct the proper heat at which the balance should be welded. When the sixty were completed the axes were turned over to the finish hammerer, this operation being done under the direction of the salesman. The axe maker insisted upon this. He considered it an improvement that all axes he made had to go through. After this operation was completed the proprietor stood by while all were hardened, and then took hold of the testing hammer himself, with the expectation of seeing a deluge of ten-dollar bills result from his tests. The salesman had barred No. 21 as one that was not welded and forged under his direction; but, according to the man, it was welded at the same heat as the others originally complained of, or perhaps a trifle hotter. This be-



Cut No. 36.

This is No. 21. Note the semi-circular checks near the edge of the axe and the two prominent ones at the edge of the break.

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ing laid on one side fifty-nine remained for the test, which was severe in the extreme; so much so that six bits were broken, showing a solid break with no trace of a flaw in any of them. At the end of the test fifty-three good axes remained, all of which had been subjected to more abuse than any axe they had ever made before would stand, according to the workmen's unanimous opinion and the frank admission of the proprietor. The No. 21 was then brought forward for test, and it broke at once, showing twelve distinct black drawing checks with the accompanying slightly rusty hardening cracks radiating from them, ending with the clean break. (See cut No. 36.)

The fifty-three axes were then ground and finished up, and then further subjected to every conceivable test that are given axes in actual use, and finally pronounced by the proprietor the best he had ever made. The man who did the welding and the forging having said that he could use the steel to greater advantage than the old, and that he could weld and forge many more axes if permitted to use the steel as shown by the salesman in making this test lot, the proprietor said he was fully satisfied that the steel was all right, and would use it and order more.

The salesman thinking the matter settled goes on his way rejoicing. At a two weeks' interval he receives another letter from his firm, saying that the steel in question had all been returned minus what was used by your man in making tests, and while the steel might be all right they required one that does not have to be worked by an expert in order that good axes may be produced. Again the salesman calls and asks what the trouble is, and why they repudiated their promise to keep the steel and use more, and is informed that they do not believe that a steel that will bear working so hot is fit to make axes from, and

that the proprietor was much surprised when his welder showed him the heat at which the axes tested were welded and the bit drawn out, and he did not want his men to get into the way of heating steel so hot, even if they did make better axes than ever before.

It is significant, however, that the fifty-three axes made from the steel returned were sent out to nearby customers under a special mark, and inside of one year they had orders specifying the axes of this special mark, and were compelled to acknowledge that they could not make as good axes from their old steel. Consequently they ordered some steel said to be similar from another maker than the one they returned the original lot to as useless to them. This is an example of what the steel maker has to contend with in introducing his product when brought in contact with deep seated and unreasoning prejudice, fostered by antiquated notions handed down from the Dark Ages.

Drop forging of high grade tool steel can only be done successfully by using the utmost care with every piece in heating just so and striking it at the right heat. High carbon and even high alloy steels have been successfully drop forged, but it could have been done only with the greatest amount of care. The ordinary process of heating several pieces at a time and smashing them into shape between two dies is a process not beneficial to a high grade tool steel, all ideas to the contrary notwithstanding. Steel of a high temper must be handled with care from its inception up to the time that the tool made from it is worn out and consigned to the scrap heap as a fragment too small for further use.

Smashing the molecules together from several different directions at the same time will never do as a common

practice on high grade steel. For while it is possible to accomplish this with proper care, so that satisfactory results may be obtained by a not too exacting customer, a very large percentage of the working quality of the steel is lost.

CUTTING STEEL COLD, IN TOOL LENGTHS.

CHAPTER III.

It is a common practice in some localities and in some shops, when a piece of steel is required for some special tool not already at hand, to go to the blacksmith shop or to dealers and have the required piece cut cold from the right sized bar. This is done by nicking the bar round its circumference on four sides with a cold chisel, and then breaking it with a sledge at the point so nicked. This is a most disastrous proceeding for any good steel that is worthy of being made into expensive tools. Nine times out of ten it strains and shatters the structure of the steel to an extent that makes it worthless in many cases, and in nearly every case deteriorates its quality far below its proper standard. Many a good steel has been condemned because it did not give satisfactory results under this sort of treatment. Very often a piece cut in this manner, worth only a few cents, has had many dollars' worth of labor expended on it in shaping it into the required shape of the tool desired. When the tool was finished and ready for hardening it has had the appearance of a perfectly sound tool, but when hardened a section has jumped off in a manner perfectly unaccountable to the man who was doing the hardening, who was willing to swear that he had the most perfect kind of an even heat when it is suggested to him that he got one side too hot. An examination of the piece that has come off and a comparison of the grain, when it is broken afresh with another fracture made on spoilt tool, shows that the

man was right in his contention, and the cause of the break is laid at the door of the steel maker with the remark that "the steel must have had a flaw in it." Often the same thing is done over again, and the steel is condemned as unfit for use as being full of flaws. The writer has known no less than five different steels, all of them good ones, being condemned from this cause before it dawned on the users that they were to blame and not the steel.

Unannealed steel when treated in this way, and the piece annealed after being cut, will sometimes show this defect when being worked so that the piece is discarded before much work is put on it. This, however, is not always the case.

Annealed steel should never be cut this way when the working part of the tool comes near the point where the steel was cut, or if it is designed to harden the end next to the cut. If no cutting off machine or power saw is available to cut the required lengths, the steel should be taken to a blacksmith's shop and heated and cut hot, and then annealed; but this plan is a poor one for annealed steel, as reannealing it may detract from its quality. The best way to cut steel for expensive tools is with a power saw running dry, so that the appearance of the surface made by the cut can be carefully noted by the operator and a sharp watch be kept for stars and spots indicating unsound steel. By using a sharp and free cutting saw, that cuts clean and leaves surface like satin finished silver, these defects can be detected in ninety-five per cent. of the pieces so cut, providing they are not over 1 foot in length and both ends of the piece are so cut and examined. The next best way is to cut the pieces off the bar in a cutting off machine.

The writer was called upon once to explain why all the dies made by a manufacturing jeweler from a certain steel broke in hardening or soon after being put in use. (See cut No. 37.) The pieces of the broken dies were carefully examined, and the grain and the general appearance indicated that they had not been either overheated or unevenly heated. On the contrary, the grain was fine and close and showed every indication of a tough, fine steel, just such as would be desired for the purpose intended. The furnace used in heating was in-

Cut No. 37.

A sample die made from a piece cut cold, with sledge and cold chisel. Note the crack, which *is not* in the part most likely to crack from uneven heating or strains This crack was started when the piece was cut.

spected the bath used in quenching and the dies were also examined, and to help the investigation the tool maker heated and hardened a piece in the same manner as was applied to the dies with a degree of care that would suit the most exacting. Inquiry was made for the bar that the piece in question was cut from, which revealed the fact that they did not buy the bar, but bought the pieces from their supply man as they needed them. As the sizes that they required were numerous, and not much of each size was wanted, they bought the various pieces as the varying demands of their business called for, some-

Cut No. 38.

Two pieces showing the result of an attempt to cut a piece of die steel cold. Note the sledge marks plainly to be seen on the face of the piece and the resulting fracture.

times getting one piece and sometimes several of different sizes, the dealer cutting them as wanted and charging them an advance in price for so doing.

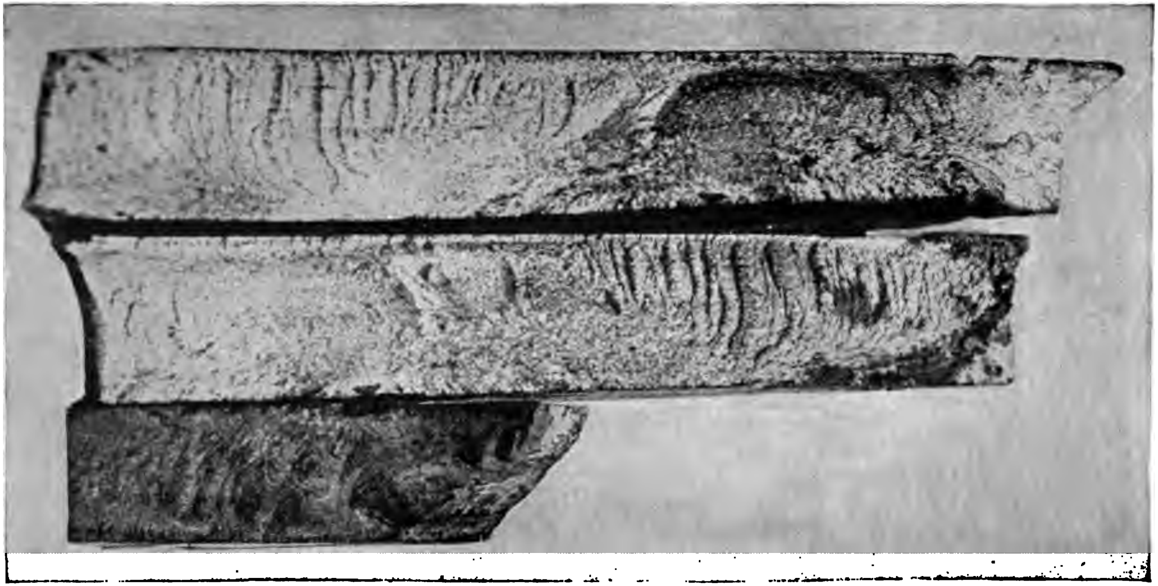
The suggestion was made that they send their man to said dealer for another piece from the same bar that the last broken die was cut from. They did so and it was found that the dealer's method of cutting these pieces was to lay the bar on a rough block of cast iron which he used for cutting all sorts of material on, such as band iron, horseshoe iron, hoop iron, etc., and while one man held the cold chisel the other struck it with a twelve pound sledge, nicking the piece entirely round on all sides. After this was done a couple of pieces of small half round iron were laid on the block, and the bar in turn placed on these so that the nick was over a line of the center distance between them, then the strong man with the sledge struck a heavy blow over the top nicking. If one blow did not break the piece others were administered with increasing power until the piece broke somewhere, sometimes at the nick and sometimes elsewhere. In this particular case two pieces were broken off after several blows had been struck (cut No. 38 shows them, and the marks of the sledge blows are shown plainly), the two pieces being produced by the desired piece breaking lengthwise as well as crosswise. By close observation of cut No. 40 it will be noticed that a line penetrating about one-sixteenth below the surface shows a different appearance to the remainder of the fracture. This line in the original piece shows a higher crystalline color than the remainder of the fracture, the particles having that bright appearance peculiar to crystallization from shocks and vibration, in which the molecules seem to lose their hold on each other and rub against each other until the

surface assumes the polished appearance described above. This appearance of crystallization is crystallization pure and simple, caused by the repeated blows of the sledge used in breaking the piece from the bar, and was the starting point of the break. There is no doubt that if the blows had been continued before the final rupture took place this line of crystallization would have penetrated deeper. (*See cut No. 40.)

* Since writing the foregoing the writer has read a statement in a book written as a guide for steel workers some assertion in regard to cold crystallization of steel, and has heard the same contention made by some others who should know better. Hence the insertion of the following remarks. It has been asserted by some that no such thing as cold crystallization can occur in steel, and that "any of these defects of crystallization are due to improper treatment in forging." That the contrary is the case there is abundant evidence to convince the most skeptical. That this point of crystallization in steel is its greatest drawback and hindrance to its use in hundreds of places is a fact well known to well posted engineers, as is also the fact that this weakness in this respect is not confined to any grade of steel, from the cheapest to the highest priced. In fact, it may be expected in any sort of granular material of a non-fibrous nature. Any locomotive builder who has had much experience in finding the most serviceable material for "stay bolts" can confirm this statement. Many other instances can be mentioned in every-day practice where steel of every grade has been found to crystallize, and it has become necessary to find a substitute in some other metal. Many other cases might be cited to prove this contention, but the one just mentioned will serve the purpose so far as low grade steels are concerned, and the broken piece first mentioned is an example of how a high grade steel will work in regard to crystallization. The evidence is plentiful and beyond impeachment. It is not the writer's purpose to enter into an argument here on this point, but the fact that this assertion, contrary to existing knowledge, has been made and printed in a work especially designed for steel workers, and that it is a flat contradiction of the facts mentioned in this chapter, it becomes necessary to insert these remarks in defense of arguments advanced in this chapter.

Cut No. 39.

Another piece from the same bar as that shown in Cut No. 38. Note the strength shown in the clean fracture of this piece broken from the corner of the bar.



Cut No. 40.

Edgewise view of the three pieces shown in Cuts Nos. 38 and 39. Note the strength shown in this clean fracture of sound steel, also the crystalline appearance along the edge of the pieces, caused by the severe shocks received in breaking.

ANNEALING STEEL. VARIOUS METHODS EMPLOYED.

CHAPTER IV.

The demand for annealed steel from manufacturers who make their own tools, and some who make tools for the market has opened up a field of investigation that some of the steel manufacturers seem loath to enter. As a result of this antipathy on the part of some of the leading steel makers the number who furnish properly annealed steel is small in comparison with the number of makers who advertise to furnish annealed steel.

As regards the question of annealed steel, the American makers are unquestionably ahead of any, as they have taken more pains to comply with the requirements of the customer, and they have not been handicapped with antiquated ideas handed down for generations in the old countries.

There is not the slightest doubt that our English cousins have lost millions of dollars' worth of trade owing to their obstinacy about this very point and their adhesion to the old fogy idea that to anneal steel soft was to spoil it, at least to a great extent. There is no doubt some basis for this claim when the various methods used and still advocated in some quarters are considered. What these various methods were is not worth enumerating here, but it may suffice to say that they consist in various methods that did deteriorate the quality of the steel largely, such as heating extremely hot and then covering up to cool off in various substances that often imparted undesirable

qualities to the steel, and in other cases absorbed a large percentage of the carbon from the piece being annealed. These methods not only injured the steel by overheating, but the material used to induce slow cooling also contributed its part toward destroying the working qualities of the steel. The first tool steel to be annealed properly in quantities in a systematic way with an attempt at uniform results was done by a Massachusetts manufacturer of fine tools, if the writer's information is correct. In this case the steel was purchased in long bars and cut up into the required lengths in a cutting off machine. The pieces were then dried and packed in cast iron boxes, made on purpose for this use, with ribbed sides and bottom to prevent warping and to allow a circulation of heat. These boxes were packed as follows: a layer of ashes was put in to cover the bottom of the box to the depth of half an inch, a little pulverized charcoal was then sprinkled over the ashes, on top of this a close layer of the pieces was laid, and these in turn were sprinkled with the charcoal, and so on in turn until the box was full within an inch of the top. There followed another final sprinkling of charcoal covered with a thick layer of fine ashes, and the box was ready for the furnace. The ashes used in this case were used over and over, enough accumulating at each heating from the added charcoal to replace what was lost in each heating, or nearly so. It was claimed that the amount of charcoal added prevented the loss of carbon by absorption to the ashes, or if any was absorbed it was the extra amount added by the charcoal. At any rate experiments were repeatedly made to determine this point and a chemical analysis made from a marked piece after annealing showed exactly the same percentage of carbon as filings taken from another piece cut next to the

annealed piece from the same bar. Pieces were also sampled for analysis before and after annealing and very little variation found. These boxes were put into oven furnaces, and after several were so placed the remaining space was filled with charcoal and the heat applied from a coal fire. The results were so satisfactory from this method that we believe that it is still in use at the works in question. The shipping room of the present works contains several more square feet than the entire works contained when this plan was started, and the products of the factory are known the world over.

Another New England manufacturer conceived the idea of saving the extra work entailed by cutting up unannealed steel into short lengths and bought his steel in bars of multiple lengths so that he could cut them in two or more long pieces. These he placed in large tubes closed at one end and filled the intervening space with lime, after as many bars as could be entered were placed therein. These in turn were placed in parallel rows held in position with cradles, and the empty space between was filled with charcoal and the heat applied. It was found that very satisfactory results could be secured by carrying a heat at a certain point for a space of time varying somewhat according to the size of steel bars to be annealed, and then allowing the fire to die out slowly, and allowing the tubes to cool where they lay in the furnace with all drafts shut off. The results were satisfactory to the manufacturer and apparently so to his customers. The steel annealed in this way was found out to come out of the lime with all scale removed and to have a silvery white appearance. It was also found to be very soft and easy to work, and, when hardened, contracted about the same each time. This manufacturer thinks that he is

using a higher tempered steel for his tools than any of his competitors, and it may be so when received from the mill. But it has been stated that the extra amount of carbon that is in the steel when purchased is absorbed by this method of annealing and sometimes more than is desirable. Whether this is the case or not the writer cannot pretend to state, as he has not sufficient personal knowledge of the case. However, the fact remains that this manufacturer is quite successful and has a good *clientele* for his tools. The possibility exists, nevertheless, that absorption of carbon does take place, and that the success mentioned may be due to other causes than the supposed extra amount of carbon. Then, again, the extra may be the saving point of the process, that perhaps would spoil a milder steel for the purpose intended. These are points that each man may determine for himself in his own way and to his own satisfaction.

This proecss has its defenders and detractors. Among the former is one of the leading steel makers, who have adopted the process for their works and who certainly do a large business in annealed tool steel. Whether they have a system by which they allow so much for loss in the annealing process and have it so nicely adjusted that they can lose so much and no more, or not, is a mill secret which we are not in possession of.

One of the methods that has much claim for it, and with good reason, is the gas process, which consists in using large air tight tubes of sufficient length to accommodate bars as long as desired. After the bars of steel are placed in the tubes the air tight head is adjusted, and to this head is connected a gas supply pipe. This head is also supplied with a small vent hole, which can be closed when desired. The long tubes are then placed in a large

oven furnace and the heat is then applied. As soon as they become hot enough the gas contained within prevents oxidation and permits the heat to act directly on the steel. It is claimed for this process that it is the only known way to anneal long bars uniformly. It is also said to be an economical process, as it is claimed that the consumption of gas is small after the tubes are once filled, as the back pressure prevents a greater flow of gas than the confined combustion can consume, which should be small. The main drawback about this process is that it requires better judgment than is usually employed in this work, and if not properly handled it may be dangerous to use, as well as expensive, for the plant costs too much to be replaced often. If this process is used under the direction of a good man, who will see that the heat is applied right and for the right time and no longer, we think that this is the best known process, as well as the most economical for producing uniformly annealed steel for any purpose that is required. (This process is patented.)

A substitute for the foregoing is used in the following manner: Sealed tubes have been used as in the former, but instead of gas being connected with the inside, a handful of resin has been put into the tube before charging with the bars and another added when the bars were placed before closing the end. Highly satisfactory results have been secured when the bars have been separated so that they did not touch each other or the inside of the tube, by a series of racks having a slight contact, thus allowing a free circulation of the gases generated from the resin. It has been claimed that this proecss does fully as good work as the other; but as the other does nearly perfect work and is under better control, especially if a pyrometer be used, this may be questioned.

The obsolete way of piling a heating furnace full of bars and heating as many as possible at a time, and then pulling them out when red hot and rolling them into an ash pit to be covered up to cool, has long since failed to fill the requirements of leading consumers of annealed steel. The same may be said about the method that fills the bar heating furnace with a pyramid shaped pile, and heating it as hot as possible and then allowing it to cool off. This results in several distinct kinds of annealing, according to the location of the bar in the pile. This method is still practiced by some steel makers, who seem to think any old thing in the shape of annealed steel will fill the bill.

The way that seems to give the best results for annealing bars in quantities, outside of the gas and resin process, is to fill large tubes with bars, filling in crevices with a mixture of equal parts of fine dry ashes and of ground charcoal, and closing both ends tightly as possible with caps and fire clay. These are heated to a degree indicated by a pyrometer, as may be required, and this heat is held for such length of time as the size of the bars may demand. The tubes are then taken out and buried in fine dry ashes. If the fuel used for heating the tubes is gas, and the pyrometer is watched well, so that the heat may be kept well in hand, this process should produce nearly, if not quite, as satisfactory results as the confined gas heating process. In fact, some who use this process claim that they can produce better results with it than any known way and with less injury to the steel. This is simply a matter of opinion. It will be observed that this is the process practiced by our Massachusetts friend, only on a larger scale and with the aid of a pyrometer and gas.

Another strange thing is the claim of some mechanics that they have never found a process of annealing steel that worked as well in cases where it was important that little change as possible take place in hardening as the time honored water anneal. This process, which is described for the benefit of our young friends, consists in heating a piece of steel red hot and allowing it to cool off to a black heat just hot enough to set fire to a piece of dry wood to the extent of making it spark when drawn or rubbed quickly across the steel. Be this as it may, one thing is evident, which is that there still remains much to learn about the science of annealing tool steel properly, so that it will work to the best advantage of the consumer. The main points seem to be to produce annealed steel that has lost none of its qualities, that will cut freely, that will not contract nor expand much, and, in short, possess all the points of steel not annealed, with the added advantage of being soft to work. That this result will be attained in the near future seems probable. The methods mentioned above are the ones that come the nearest to that achievement at present. The many others are not worth mentioning, as most of them do more harm than the best steel maker could undo in a lifetime. It may not be out of place to say that the man who persists in double annealing and reannealing steel does the most harm.

PREPARING STEEL FOR HARDENING.

CHAPTER V.

Some remarks on this score may be of some advantage to the young tool maker, who usually has to learn many points by experience that is sometimes costly and trying to his patience. One of these points, often overlooked by tool makers who should know better, is the fact that the smoother a piece to be hardened is finished the harder it will harden. It will also harden deeper when finished smooth than a piece left rough as coming from the turning or planing tool. It is also often of vital importance that no deep scratches or cuts are left in a piece that can be taken out of it, or that any sharp corners should exist at shoulders rising from one size to the other. These deep scratches, cuts and corners make the best kind of a starting point for a crack. All shoulders should be finished with round corners where it is not of vital importance to have them square, as in Fig. 41. Scratches and cuts when carelessly made should be carefully removed where possible, in other cases smoothed down.

Large pieces of flat steel with many holes in them should have all the small holes filled with fire clay or some substitute before heating, if heated in an open fire.

All small holes and holes counterbored, or partly drilled through, should be carefully and smoothly reamed to take out any circular scratches made by the drill or counterbore, especially the bottom of holes.

Cut No. 41.

A large formed milling cutter for milling teeth in large gears, and a small one beside it for comparison. A very hard piece to harden properly. Note the round half circle at the bottom of each tooth, doing away with the square corners which are the favorite starting point for cracks.

The number of costly dies and pieces lost in hardening from a simple scratch or tear made by a drill and left in the piece because it does not interfere with the working part of a tool is beyond computation.

Take pains to have even the bolt holes of a large flat die smooth as possible to get them before hardening.

In large square dies, such as are used for drop forging, drill as large a hole as is consistent with the size of the die two-thirds of the way through from the center of the back toward the face, and follow up the drill with a round lipped rose reamer to its bottom, to take out all tears, scratches and the sharp corner left at the bottom by the lip of the drill. Some advocate drilling a hole through from one side to the other, instead of the hole in the back of the die. This plan has no advantages over the other in ordinary forged die blocks, but where the die block is cut from a large bar and the die made up so that the front and back come on two of the sides, and the hole can be drilled to go lengthwise the bar, it is undoubtedly a good plan, as it will partly or wholly remove the defective center, if any exists; or, if in case it is too large to be so removed, it can be detected by examination after reaming and guarded against as far as possible.

For large steel rolls drill as large a hole through the center as can be done without weakening the roll any, and ream it out with the utmost care, getting a surface as though you were making it for government inspection. When this is done lay the roll on the bench, and after cleaning the hole from all oil, etc., inspect it for scratches and defects in the steel; if any are found, counterbore if necessary and ream again, or ream with a larger sized reamer until defect is removed. See that every shoulder is filleted or round cornered and free from all scratches

and tears. (Cut No. 42 shows solid roll.) If the hole shows perfectly sound and clean steel leave it open when heating; if a suspicion of a defect remains stuff it with fire clay, which should be removed when taken from the furnace and a liberal dose of oil administered before quenching. All large round pieces may be treated in this way when a hole is not objectionable. (Cut No. 43 shows same roll as No. 42, after hardening might possibly have been saved by drilling hole.) For taps, reamers and all parts having crevices not easily wiped clean with waste, and intended for heating in hot lead, dip in salt

Cut No. 42.
A roll made of unsound steel ready to harden.

brine and allow to dry before inserting in the hot lead. This will prevent the lead from sticking to the teeth and save considerable time otherwise required to remove the cold lead. When you have a quantity of small pieces that are required hard all over, which can be conveniently wired together, do so, putting from six to twelve in a bunch, according to size and shape, and leave a loop of the wire projecting upward when packed for heating. This enables the hardener to withdraw one bunch at a time from the hot ashes, and while in hand give them a circular swing in the bath before dropping them, thereby

giving better results than otherwise, as pieces dumped into a bath often stick and fall together in such a manner as to prevent even hardening. The method of taking hold of each piece separately with the tongs has the same drawback.

For hardening pieces of mild steel where one part is required moderately hard and another part as hard as possible, pack in rows with a trough made of sheet steel or iron, adjusted to the part required hardest. Pack this with a paste composed of equal parts of cyanide of potash, wheat bran and pulverized charcoal, mixed with water. Fill around the remainder of the piece with pulverized charcoal. You can vary the amount of cyanide as required.

For drawing dies and sizing dies where as much wear as possible is wanted in the hole, pack the hole solid with a paste made of bran and cyanide of potash, and do not wire through the holes used for working parts, but pack closely together, filling in all remaining space with charcoal dust. For triblets, cams, etc., nest the wearing part in same paste freely and surround with charcoal

In packing engraved dies for hardening select a box that will leave you a full inch all around the die, place about three-quarters of an inch of pulverized charcoal in the bottom of the box; over this at the point covered by the impression and engraving of the die place enough flour of burnt leather to fill the engraved impression, then place the die in the box, carefully pressing down so that the burnt leather is forced up into the impression, so as to fill every line of the engraving. Then fill all around the die with pulverized charcoal, covering the top part with a layer at least half an inch thick.

Cut No. 43.

Same roll as shown in Cut No. 43 after hardening. Examination of fracture indicated that this roll might have been saved by drilling a hole through the center, which would have removed the greater part of the defect.

For perforating and similar dies containing a large number of small holes, make sure that the holes are clean and free from circular or vertical scratches made by withdrawing the drill or reamer when not in motion. Be sure and pack these dies with the part down toward the bottom of the box that has the greater portion of solid steel in it.

In preparing hollow shells like belt punches, wad cutters, tinner's punches, pearl cutters, etc., for hardening make sure that no scratches, either lateral or circular, remain either inside or outside, as they make a starting point for a crack and prevent uniform hardening.

Avoid making slender points on formed tools, where they can be ground into the desired shape after hardening without disturbing the shape of the tool elsewhere.

Avoid deep centers and deeper drill holes in centers, especially in reamers and other tools with little body of steel around the centers below the bottom of the teeth.

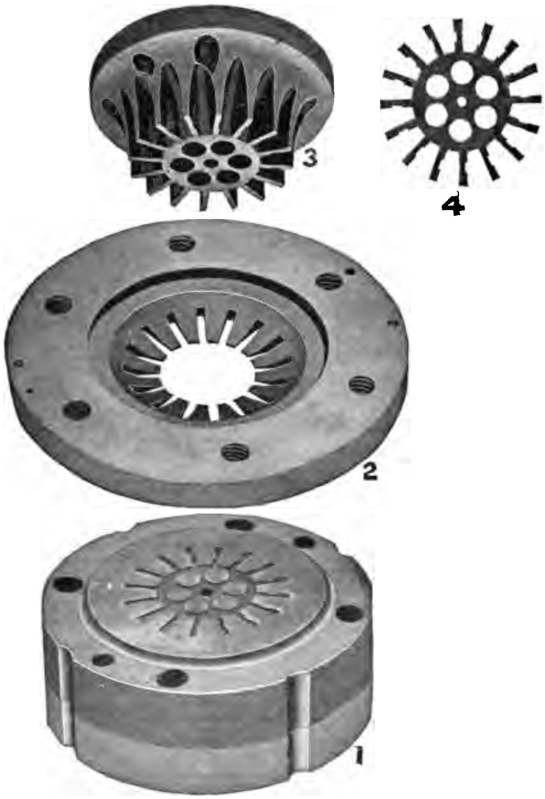
Avoid plain drilled dowel holes in large, flat cutting dies near the working part or corners; drill through and ream carefully when practical.

In drilling to tap for screws to hold stripper plate drill through the die, when not injurious to do so and when not practicable, drill nearly to the desired depth, then remove the drill and grind the corners rounded and sharp and the point blunt, and drill enough deeper to remove all marks of the former drilling from the bottom.

In tapping do not run the plug tap within one-quarter inch of the bottom if not necessary; you can let the tapper tap bottom without danger. (See Cut No. 44.).

In preparing any tools for heating to harden see that all traces of moisture are removed, especially if the heating medium is to be hot lead.

In pieces to be hardened that have counterbored screw holes in them avoid all acute corners at bottom of the counterbore. Instead see that each corner has a fillet equal to the quarter segment of a small circle, according



Cut No. 44.

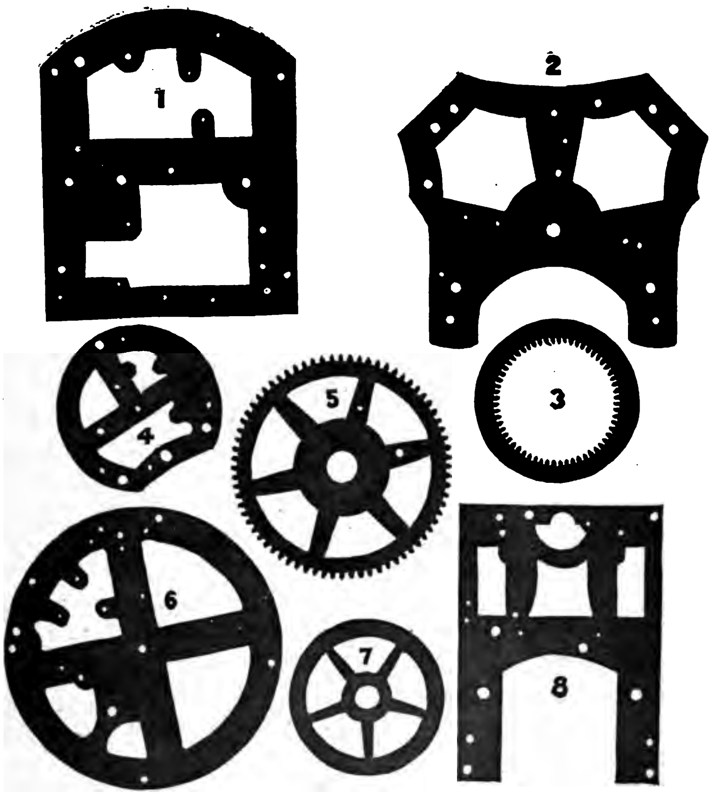
Pieces that require great care in preparing and in hardening. The set of sub-press tools and their product, consisting of No. 1, the die and lower punches; No. 2, the stripper; No. 3, the upper die and punch; No. 4, the piece produced in one blow. Cost of steel about $2.50; cost of labor expended, $250.

to the size of the screw head used, and in order that the screws may have a full bearing at the bottom of the counterbore remove the corresponding corner of the screw head to fit the round corner at the bottom of the counterbored hole.

In packing pieces with two sizes that are long and liable to warp in hardening, which are required hard all over, start the bottom layer by putting two or more pieces of sheet steel bent so as to form supporting points for the smaller end to a hight of one-half the difference in the diameter. After placing the bottom layer reverse the second one and each succeeding one, sprinkling each layer lightly with charcoal dust. Fill the box according to the size and the weight of the pieces, and put a good layer of pulverized charcoal over all, jarring the box to shake down as much as will penetrate between the pieces. If this is done with a little care and the smith dips the pieces properly, it will be found that the pieces have sprung very little.

In preparing sub-press dies for hardening, where too large to grasp firmly on the outside with the tongs, it is a good plan to wire them in a sort of sling that can be grasped with the tongs so that the piece will lie perfectly horizontal in entering the bath, so the water will strike the whole surface at once, and every hole will be perpendicular. (See cut No. 45.)

If it is desired to harden hollow mills, spring threading dies, etc., by packing, they should be packed standing perpendicularly on their working end and with only one layer in a box, care being used to select a box with a level bottom. After placing as many as the box will hold fill with ground charcoal.



Cut No. 45.

Eight sample pieces of work produced by sub-press dies in one operation each, complete as shown. Highest priced steel known to make the tools for these pieces would cost about 2 per cent. of the labor cost of making the tools. Nos. 1, 2, 6, 8, clock frames; No. 3, hollow gear; No. 5, gear with teeth punched in it; No. 4, small clock frame; No. 7, a gear blank.

Cut No. 46.

Eight sections of a piece of high grade steel heated at a varying heat, hardened, and broken to show the grain; No. 1, at the left-hand upper corner, showing the point heated hottest and No. 8, at the lower right-hand corner showing the point not heated hot enough to refine, showing natural grain; the second one in the lower row showing the best refining heat.

Cut No. 47.

Piece broken from 2-inch plug gauge 24 hours after being hardened, ground and finished to size, jumped off while lying on the bench with no one touching it. Is an example of first-class hardening, the fine dark ring on the outside showing the depth of the hardened shell. Cause of the break, a small interior pipe closed up.

HARDENING AND HARDENING APPLIANCES.

CHAPTER VI.

The question of hardening steel that is dependent on baths after being heated to the proper heat has been discussed at great length by abler men than the writer, and it would not be mentioned here if it were not for the fact that in giving profuse and explicit directions about baths, furnaces, etc., some of the vital points have been omitted.

In the first place the simple statement that steel to be hardened so as to be at its best should be hardened at the lowest heat at which it will harden hard as desired and show the finest grain when broken. (See cut No. 46.) If this is done the method used in heating and the bath used in quenching are of secondary importance. The particular furnace used does not matter as long as it heats the steel uniformly and evenly, without injury from air blasts, sulphurous fuel, etc. The particular bath is also of secondary importance as long as it is capable of quickly cooling the piece to the desired hardness. Should we stop here it would seem that we had said quite enough on the subject, but a hundred questions arise in the mind of the reader about what to do in such and such a case.

We will answer some of them to the best of our limited knowledge.

First, in hardening large pieces allow them to cool entirely through before removing from the bath. Do not take them out with the idea that you will draw the temper to the required point with the heat still contained

in the piece. If you do you must not blame the steel if the inner heat cracks the hard, unyielding outer shell. If the piece cracks in the bath while cooling you may be sure that you either got the wrong heat or that the steel maker gave you an imperfect piece of steel which probably would have broken anyway. (See cut No. 47.)

If you have a piece with a large and small part that is required hard all over be sure and watch the small part in getting your heat, so that in getting the larger part hot enough the small part does not get too hot, thereby producing an uneven heat and consequently a strain which will develop into a crack sooner or later, probably sooner.

Two kinds of baths are advisable for pieces having a small part that it is vital should be hardened at its best, it being the important or working part of the tool or piece, as the case may be, such as a milling cutter or circular cam with a number of projecting points. One bath is used to cool the small parts quickly as hard as required. To do this before the larger part has cooled to any great extent produces the same effect as an uneven heat, a strain or crack if the piece is left in the bath used for hardening the small part. (See cut No. 48.) To avoid this have another milder bath handy to change the piece into quickly, and allow it to remain until entirely cold. Objection to this method is made in some quarters by those who think it dangerous to remove a piece from one bath and place it in another, and who say that there is no use doing so if the piece is properly heated in the first place. This is true to a certain extent, but it must be borne in mind that it has never been known to work harm, and that this work is not designed as a guide to those who have had long years of experience and who

Cut No. 48.

A milling cutter 4 inches in diameter hardened in a hardening compound and left to cool entirely cold in it. The result is seen beside the cutter. The teeth that have not come off will do so with a slight touch or blow.

Cut No. 49.

Three samples of hardened steel, from left to right good, better, best. All three of these show a very fine, close grain. No. 2 from left to right shows more strength, No. 3 still more, while being equally fine in grain as the others. From three different makers at same price.

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are provided with all the modern appliances for heating and quenching to be found in the hardening rooms of the large manufacturers of fine tools for the market. On the other hand, the writer has met many a manufacturer who has asserted that he found that his own tool makers made tools that did much more service than any he could buy, and this same manufacturer has had none of these improved appliances, but simply an ordinary forge and tub of water flanked with a tank of oil. The work that the writer has seen done with these simple and crude appliances has filled him with wonder and confirmed the idea that in the American mechanic we have the best and most resourceful workman in the world. (See cut No. 49.) It must also not be lost track of that perhaps these manufacturers may be using a much better steel in some cases than the maker of tools for the market considers it policy for them to use; but even this does not account for all the results claimed, as many of these manufacturers are using exactly the same steel as the maker of tools who supplied him before he found it best to make his own.

For those who are not provided with better appliances for hardening and who are compelled to heat large pieces in an ordinary forge, the fire should be well banked up with soft coal and thoroughly coked into a mound large enough to form the roof of an oven like structure when a hole is made in the front of it with capacity large enough to admit the piece to be hardened. Then a good solid bottom should be formed of well coked coal or coke, the piece to be hardened inserted and surrounded with charcoal or coke, care being taken that the bottom of the fire does not burn away, and thus allowing the blast from the tuyere to come in contact with the piece. It is well to stop up the hole in front, or nearly so, in order that the

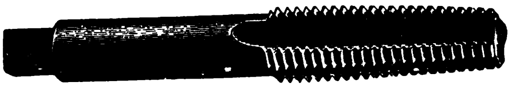
piece does not become hot on one side before the other, and that all the heat possible may be retained inside the oven. When the piece is nearly hot enough shut off the blast and let the heat even up to the proper heat. Remove from the fire deliberately, and with no undue haste plunge slowly to the bottom of the tub of water or brine and withdraw it slowly, and as soon as out of this bath plunge it quickly into the tank of oil and let it remain until cool. Judgment must be used in the plunging according to the size of the piece, the idea being to thoroughly chill the teeth or working parts and at the same time not chill the base of them to the contracting point, or, rather, to the point where the contracting ceases.

If this is done properly on a milling cutter, for instance, the thin part of the teeth will be thoroughly hardened as far down as they are ever used; the base of the teeth will be black hot. There will be a ring around the hole in the center of the cutter. Between this ring of apparently cold steel around the hole and the similar ring at the base of the teeth the steel will glow a dark red, showing that the main body of the cutter is still hot. The first bath will have produced the required hardness in the working parts, the second will hold what hardness we have and slowly cool the large, solid ring of steel that forms their base, without producing strains which cause the corners of the teeth to jump off. These strains are caused by the thin part becoming entirely cold and ceasing to contract before the thicker or larger body of steel reaches the same condition. It continues to contract, or, in other words, the larger portion of steel continues to move after the lesser portion has stopped moving, and as a natural result they part company.

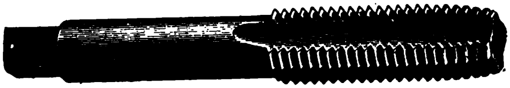
Another way of hardening complicated shaped small milling cutters is to heat them from the hole in the center outward, and quenching them the same way (from the center) beyond the danger point of fracture, and then immersing them to cool entirely off. This requires special appliances and has the objection of shrinking the hole, in many cases necessitating grinding it out; but some shapes require this treatment.

The best heating appliances known at the present time for heating large pieces are the gas muffle or oven fur-

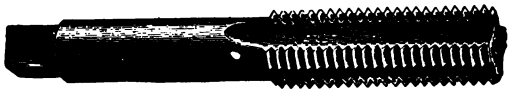
Taper



Plug



Bottoming

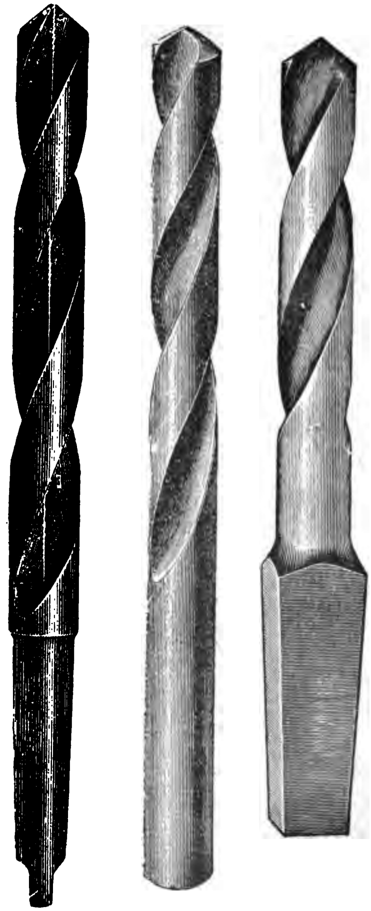


Cut No. 50.

A set of machinists' taps which should be made of a high grade of steel. Alloy steels can be used to advantage in making these if they are going into the hands of careful men.

naces, the former for pieces not over one pound in weight and the latter for large pieces and boxes containing small pieces. These gas furnaces seem to give the most uniform results, especially on pieces required to be hardened all over.

For many tools and parts the red hot lead pot is superior to any other known method. Among this class may be mentioned taps, reamers, twist drills, etc., also



Cut No. 51.

Three styles of twist drills, taper shank, straight shank and shank for a bit stock. The first two require best steel obtainable consistent with hardness and extreme toughness combined. For the bit stock drill, which is not subjected to anywhere near as severe work as the others, a cheap steel may be used with satisfactory results. Heated for hardening in red hot lead.

threading dies and all pieces where there is a fine edge or points that are most important. (See cut No. 50.)

In using the lead bath for heating care should be taken to secure chemically pure lead free from sulphur, etc. To prevent oxidation a thin layer of dry ashes or charcoal should be spread over the top of the hot lead. (See cut No. 51.) If a crucible is used it should be emptied after using, before the lead cools, to prevent it cracking in the cooling. A cast iron pot is to be preferred, on this account especially made for the purpose. Hot molten salt is also recommended for heating these tools and files, etc., but this is more troublesome to use and keep at a uniform heat than lead.

For large quantities of small parts or certain shaped tools packing in cast iron boxes with pulverized charcoal and heating in oven furnaces will be found the most satisfactory, and in many cases where it is desired that some particular part shall be extra hard a paste made of equal parts of cyanide of potash, pulverized charcoal and wheat bran, mixed with enough water to make it pasty and applied to the part where the extra hardness is desired, can be applied in packing the boxes better than any other way. Drawing dies for drawing tubing and other parts so treated will give an extra amount of wear.

Ground bone or bone charcoal should never be used in packing tools made of good steel for hardening. It may be used on mild steels where intended for wearing parts of machinery, but never on cutting tools.

Taps, reamers, twist drills, milling cutters, threading dies, etc., should never be heated for hardening in an open fire if best results are desired.

The best bath known for quenching tools made from good steel is plain, clear water, frequently renewed, or

running water. A tub with a supply pipe of running water and an overflow pipe is the acme of all hardening baths, especially if this tub is supplied with soft, clean water from a reservoir, tank or pond. In the winter time care should be used that the chill is taken off the water in case it is to be used in quenching tools or parts with delicate sections, which cool very quickly; but for many kinds of tools it does not matter how cold the bath is, providing you are sure that you have the right heat and a reliable steel. If in doubt about these points it will be well to raise the temperature of the bath considerably above the freezing point, according to your judgment.

When a good supply of fresh water is not available salt brine made as strong as the water will absorb salt, with an ounce of sal ammoniac added for every gallon of water, is the next best thing to use as a cooling bath. The sal ammoniac serves to remove the scale from the pieces in cooling, bringing them out clean and silvery. Sal ammoniac can be used in plain water with the same advantage. There are a thousand and one mixtures for hardening baths, but for a good high grade of tool steel nothing better than the above is known for all ordinary shop tools.

The oil bath should be arranged as follows: There should be selected a can not less than 24 inches deep, of a diameter at least 3 inches smaller than another one inside of which it sits. The bottom of this inner can or tank should be provided with projections to raise it at least an inch and one-half from the bottom of the other, and should be so arranged that when a heavy weight is placed in the inner can it will not bulge the bottom, but will allow a free circulation of water between the inner and the outer can. This point is accomplished by some

by using an independent grating in the larger or outer can, on which the inner can rests. The oil bath is essential to all well regulated shops where many expensive tools are made or many pieces of steel parts are hardened, and it will in many cases be found advantageous to have several with different oil in each. For instance, sperm oil is considered best for hardening springs and delicate pieces, while others claim that lard oil is superior for cooling large pieces and holding what hardness has been put into some parts of the piece by the water or brine bath, like milling cutters, etc. Cotton seed oil also has many friends for this purpose.

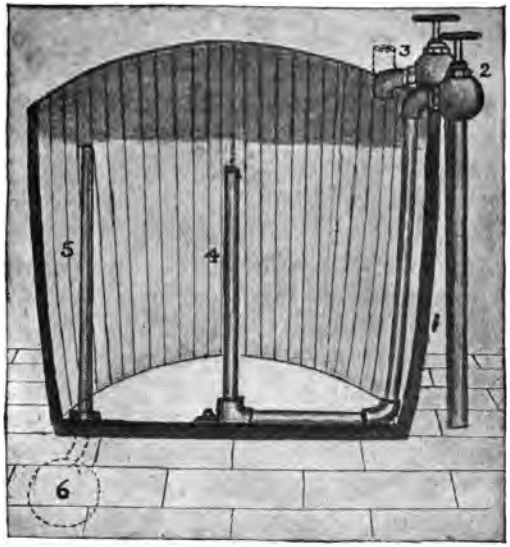
The writer was recently in a shop where they used four kinds of oil in hardening tools and parts, and claimed that it paid them to do so. The oils used in this case were sperm, lard, cotton seed and crude mineral oil. They were in twenty-gallon tanks, each provided with a cover to keep out the dirt and extinguish fire in case the oil caught from the red hot steel. These four cans were placed inside of an oblong wooden tank fitted with a supply water pipe and overflow. The wooden tank was fitted with a cover also on hinges, and each of the oil tanks was provided with a wire basket that fitted the inside closely enough to prevent any work passing it. This basket caught all work dropped into the oil, and could be raised to any point or lowered to the bottom as desired, and after the work was cool it could be raised out of the oil and suspended above the tank to drain off the oil. In this same room were three other tanks holding about four barrels each, one containing strong salt brine, another a weak solution of sulphuric acid and water, and the third equipped with running water and an overflow pipe.

This firm found it economical to use several methods of heating as well as several kinds of baths, as could be seen by a large oven furnace, a fair sized gas oven furnace, a small muffle gas furnace, a lead pot gas furnace, a small gas forge and an ordinary brick forge, all supplied with air from a positive pressure blower. In addition to the above there were a gas brazing outfit provided with four burners, an adjustable work holder and stand for same; also on a bench on one side of the room were several Bunsen burners of varying size near an oil tempering bath equipped with a thermometer.

This firm makes all their own tools and steel parts, but do not make any tools for the market. It seems to one who sees this hardening plant that the man in charge should be able to harden anything made out of steel and harden it right, and it may be presumed that he can. With all the enterprise shown by this firm in fitting up for doing first-class work, they were far behind the times in the steel they used, and instead of trying to secure the best were perfectly satisfied with the extra amount of work they had secured from a very ordinary steel by these new and improved appliances for hardening.

The best sort of a bath that can be made for general work is in a large tub at least 30 inches deep by the same diameter, the larger the better. It is shown in Fig. 53. A 3-inch hole should be made in the bottom on one side, this hole fitted with a tight pipe connected with the drain below and with an adjustable pipe above, in two or more pieces susceptible of being adjusted so that the overflow may be fixed near the top of the tub, or low down, or taken off altogether so that the tub can be entirely emptied. On the opposite side from the overflow bring up on the outside of the tub a supply of fresh water of

liberal size. At the top of the tub on this pipe place a T and extend it long enough to enable the fitting of two globe valves far enough apart to be worked freely without interfering with each other. From one of these carry



Cut No. 52.

This cut shows a half section of a tub of an approved arrangement for all kinds of water hardening. It is fitted with a supply pipe, 1, susceptible of furnishing a strong stream of fresh water in the center of the tub controlled by valve 2. By opening valve marked 3 a stream of water can be projected toward the bottom of the tub upward or sideways as the operator may desire. Is also supplied with an adjustable overflow pipe 5, center supply pipe 4, from valve 2, drain pipe 6, connected with the adjustable overflow pipe.

over the edge of the tub a pipe to the bottom, terminating with an elbow; from this carry the pipe to the center of the tub, terminating with another elbow securely fastened to the bottom of the tub. Into this last elbow fit a short

piece of pipe which has been turned to a true round; this last should extend about six inches above the elbow. Fit to this last piece in the form of a sliding sleeve several pieces of varying lengths, so that you can bring the point of inflow to any desired hight in the center of the tub. To the end of these sleeves fit such forms of nozzles as your work may require. From the other end of the T at the edge of the tub bring over the edge a short piece of pipe so fitted that it can be moved at any angle from straight down to straight up, with a slight incline when up toward the center of the tub. To this short piece fit other pieces with the ends reduced to smaller sizes that may be required for any hole you desire to shrink or harden. With the above arrangement you have all the bath that you require for any ordinary work. You have a strong supply coming up in the center to harden impressions in dies and large sized pieces. With the other valve you can create a rapid circular current by turning the pipe at an angle of 60 degrees from the perpendicular. By turning this directly toward the bottom of the tub a stream of cold, fresh water is projected downward which you can utilize in various ways. By turning it straight up you can adjust any sized nozzle required for shrinking holes without cooling the outside of the piece. (See cut No. 52.) Provide this tub with an adjustable (in hight) four-legged stand to support heavy pieces over the center stream, and you have the best possible outfit for hardening all tools and pieces required as hard as fire and water will make them.

HARDENING TOOLS AND VARIOUS PARTS.

CHAPTER VII.

In the following remarks about hardening the writer does not pretend to give infallible or superior receipts, but in the main confines himself to the various methods in use by successful firms and within the reach of all. In the preceding chapter we have described hardening appliances in general and made some remarks about hardening steel.

For the benefit of the beginner we shall begin with that much abused and indispensable tool called a cold chisel. Some smiths advocate hammering a cold chisel at a black heat to refine and toughen it, and after taking the pains to do this will replace it in the fire and heat it hotter than it was when they began to refine it after doing the heavy forging, and will heat it further up to secure heat enough to draw the temper. (See cut No. 53.) This being done they will immerse the cutting end in the bath part way up the length of the heat, and then withdraw it and polish the blade with a stick covered with emery or emery cloth, and wait for the temper to run down from the red hot part above the blade. When the desired temper shows by color, the whole chisel is immersed and cooled and then given to the man who is to use it. In this case the smith has undoubtedly undone a part of the mischief and all the good, if any, produced by his cold hammering. In nine cases out of ten he has heated the vital part of the tool too hot for good refining in getting the heavy part hot enough to draw the temper.

Any steel that will not stand this treatment and make a good chisel is condemned by him.

Let us see how a smith who keeps the tools in order for a gang of over one hundred men does it. He takes a piece the right length for a chisel, heats it to a good bright red heat one-third of its length, and on his steam hammer draws it down to about twice its finished thick-

Cut No. 53.

Three cold chisels, one properly forged and the other two checked at the edge from hammering after they were too cold. Note the curved check in No. 2 and the broken point of No. 3.

ness on the cutting end. This done, he returns to the fire and reheats it to about the same heat as was first employed. While so doing another piece is on one side of the fire getting warmed up. After getting the desired heat it is taken to the anvil and, with a hand hammer

and light sledge in the hands of the helper, the chisel is quickly shaped with the blade still red hot, or nearly so, when finished. Instead of cold hammering to refine, the chisel is again returned to the fire and the other piece that has been getting warmed up in the meantime is moved to the center also. The chisel just forged, when heated to a low red heat, is thrust into the annealing box and left to cool. All the subsequent ones are treated in the same manner, and if any are required for immediate use those first forged are selected, and if not entirely cold are plunged into water to make them so. A piece of iron is then laid across the fire, partially buried, the thin edge of the chisel is laid on this and the heat allowed to take hold some distance back and run up to the edge. The blade is then dipped and hardened well up, so much so that in most cases there does not remain enough heat to draw the temper. In this case the chisel is laid on a hot piece of iron with the edge projecting well over. If none of these chisels are wanted immediately they are left in the ashes until the next day. They are then hardened in the manner described and put on one side for future demands, and it is claimed that if they are allowed to remain several days they stand much better than when put to work at once

This, you will say, is quite a rigmarole for making and hardening so simple a tool as a cold chisel, and it is but then the question arises does the end justify the means?

The fact that this man keeps the tools in shape for over one hundred men, and every one of these men will swear that his tools are the best they ever used in any of the various shops where they had worked, leads to the supposition that there may be something in it.

This same rule, whether considered a good one or not, may be safely applied to all forged tools, so far as omitting the cold hammering and the heating of the larger parts to draw the temper are concerned.

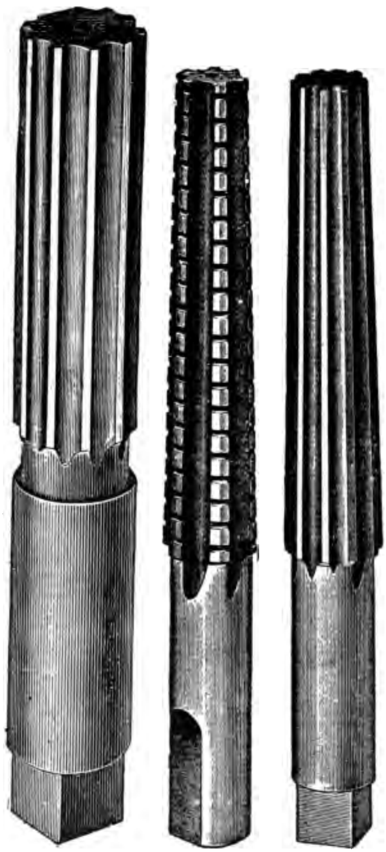
It is an established fact that many of the high carbon and alloy steels require reheating to relieve the forging strains and that they are improved by being reheated and allowed to cool slowly after forging. It is also an established fact that these steels are ruined if they are hammered much at a heat below a red. The inference is plain that the steel made nowadays does not require the old-time blister steel treatment and will not stand it and yield the best results. The high grade and most economical steels to use are made in the present day to need no refining on the part of the smith.

For hardening lathe tools which have been carefully forged and annealed to relieve the forging strains keep the working part only, checking back the heat at the points liable to get too hot before the heavier portion of the working part is hot enough. Cool in plain water and do not start the temper enough to make any color show at all on all tools that have a good backing for their edge.

A tap, a reamer, hardened at its best should be glass hard in the teeth, and at the bottom of the spline or groove should be soft enough to be cut with a graver or hard file, this condition indicating that the piece was heated in such a manner as to harden the working parts at the very best heat applicable to the steel the tool was made from Reason will tell us that it is impossible to heat the solid center of a tap or reamer hot enough to harden as hard as the teeth are desired without overheating the teeth to a greater or less degree in the operation, and the slightest

degree of overheating detracts considerably from the lasting and working quality of the tool. (See cut No. 54.)

It must not be understood that the bottom of the



Cut No. 54.

Three solid reamers showing a finish sizing reamer, a roughing taper reamer and finish taper reamer. It is economy to make these finish reamers of the best steel obtainable.

spline or grooves in these taps and reamers will not harden at all. It simply will not harden hard enough to resist a very hard file, if the teeth were at right heat, and the difference in the hardness of the teeth and the bottom of the groove in taps, reamers, etc., is readily detected before drawing the temper on the tools. For producing these results in hardening, a pot of hot lead is the best medium for heating and clear cold water for quenching. With a little practice a man who is gifted with fair judgment can produce this result right along, if provided with a good uniform steel. Taps and reamers and similar tools, heated in hot lead with proper care, can be left in the bath until cold, but it is advisable to see that they stand on end, and in no case be allowed to lie across each other in the bath while cooling, especially if cooled entirely in water or brine.

Large, flat pieces, particularly thin ones, free from numerous holes should be dipped edgewise, and if moved in the bath before cooled should be moved edgewise to avoid warping as little as possible. Large, flat pieces that are also thick and full of holes and which are required very hard should always be packed in boxes with charcoal, and when dipped should be put into the bath flatwise, with every hole in a perpendicular position if possible, and should be forced down and up sharply in the bath when first put in, to force the liquid through the holes quickly, as it soon heats and does not produce the required hardness unless forced out of the holes and frequently replaced by colder. This is the best method in the absence of special appliances for projecting water through every hole while the die is immersed and stationary. After the heat is quenched around the holes and the working part of the die it should be lowered to the bottom of the bath

and allowed to cool on some support that will hold it level. The best bath for cutting dies is plain, fresh, running water and an abundant supply of it.

Should the die be of a complicated shape with a considerable solid steel on one, two or three sides and a thin section on the others that is sure to cool quicker than the larger section, it is best to hold the piece in the water long enough, the thin side up, to chill the working edges thoroughly and then quickly remove it into a bath of lard oil to cool off entirely. This will have a tendency to prevent cracking of the thin parts from the uneven strain produced by one part cooling to the non-contracting point before the others.

The best way to harden milling cutters is to heat them in a gas oven furnace, placed endwise on thin plates of sheet steel, with the hole in the center filled with ground charcoal and a trifle around the base where the teeth rest on the plate. So soon as the desired heat is reached turn them down on side and roll gently to even up the heat, then insert a rod through the hole with a spring Y on the end of it, which prevents all chance of it slipping off in the first bath. Quickly withdraw it from the oven and deliberately walk to the bath and plunge it, end first. slowly to the bottom of the bath. After that draw it slowly upward until near enough to the top to allow you to observe whether you have a dark ring around it inside of the base of the teeth and a similar one around the hole. If these show, quickly withdraw and insert in oil bath to cool slowly as described in preceding chapter. (See cut No. 55.) A plentiful supply of fresh running water is the best primary bath for these, where obtainable.

For hardening engraved, stamping or master dies they should be heated in a gas oven furnace, packed as

described in the preceding chapter. For these dies a special shaped spout should be used according to the amount of engraved space to be covered, and the shape of the impression in the stamping dies. This spout

Cut No. 55.

A gang of four milling cutters interlocking with each other. Very expensive to make. Should be made of the highest grade obtainable of carbon steel. Should not be attempted in the high alloy steels except in the hands of the most expert hardener, owing to the numerous corners.

should come up in the center of the bath and in all cases be submerged below the surface, and the flow controlled by a valve handy to the operator. The overflow should be large enough to take off all surplus water above an

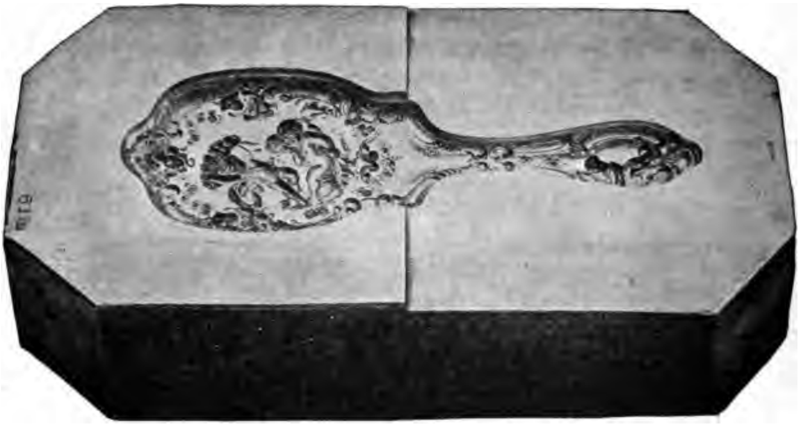
established level. Only one die should be packed in a box, and in the case of cold stamping dies the steel should be susceptible of taking a good soaking heat so as to harden deeply to prevent sinking under heavy blows. (See cut No. 57.) The whole die should be immersed

Cut No. 56.

The pair of coin dies made for coining the souvenir coins of the Republic of Cuba prior to the formation of the Republic. The value of the steel used about $2. Cost of labor, $200.

just under the surface unless it is a large square piece above five inches or an oblong one above five inches wide. In this case it is best to regulate the overflow so that the water will rise slowly and only cover it as the heat dies

out to a black. (See cut No. 58.) These stamping dies and master dies should be laid on a perfectly level plate, face up and warmed to about 400 degrees, then taken off and laid in a warm, dry place for as long as possible before required for use. Before using, the back of these dies should be surfaced off perfectly even, so that every part of the base will have a bearing on the bed plate.



Cut No. 57.
Die for making the back of a hair brush. Value of steel used, $3.25. Value of the labor, $198.

For heating all hollow shells like wad cutters, belt punches, tinners' punches, pinking irons, cardboard cutters, shoe dies and envelope dies, etc., the hot lead pot is superior to any method known to the writer for securing an even heat at the point desired. The bath used for these tools depends on the varying requirements. For instance, the tinners' punches, wad cutters, belt punches, cardboard cutters and envelope dies, if used under a press,

Cut No. 58.

Two large milling cutters 18 inches in diameter by 3 inches thick, successfully hardened without the loss of the point of a single tooth. This is a poor cut, owing to the cutters being drenched in oil when the picture was taken. Heated in a coal oven furnace.

should be hardened in water. The pinking irons and shoe dies should be hardened in oil. Heating in red hot lead is found the best for all taps, reamers, twist drills, counterbores, flat drills, broaches and, in short, all tools having a sharp, prominent edge as their vital part. Hot lead is also recommended for drawing the temper on many tools that can be hardened better by some other process, such as round and square solid threading dies, triggers, hammers and other parts of guns, and all tools and parts, one part of which is to be softened and the other left hard, provided they are of such shape as to permit of inserting the point desired soft in the hot lead. The hot lead pot will be found very useful in hardening many parts of fine machinery and manufactured articles, where a hard section is required combined with a soft one; for instance, an inserted jaw for a pipe wrench, with a projecting lug on the back of it for a screw or pin to pass through to hold it in place, and with the teeth on the face required hard to grip the work. Such pieces can be hardened better in this way, even in large quantities, than by any other method. A shallow flow of water running over a slightly inclined plate with side pieces and cross wires to hold the pieces does the business nicely.

Nothing is equal to the gas over furnace for heating large or small dies, flat, square or oblong, for all rings, whole or in sections, for all small parts which have two opposite points required hard, or desired hard all over, with one point or projection, to be softened after the rest of the piece is at the desired hardness. The next best thing is the coal oven furnace for this first operation of hardening all over, though the lead pot may be used to advantage on many kinds of work for softening and tempering as mentioned above. (See cut No. 58.)

Oil gas furnaces and oil spray furnaces are also used to advantage in many places, but some judgment and skill are required in using them, especially in the oil and air spray fed furnace, to see that the spray does not come in contact too strongly with the piece to be hardened after it reaches a red heat, otherwise the piece will lose some of its qualities and not give as good results in use as it should.

Another method of heating to harden that requires care is the gas and air blow pipes usually used in pairs, projecting a sharp flame toward each other and meeting on the piece of work to be hardened. Very complicated and expensive tools have been successfully hardened in this way, and many have doubtless been ruined by overlooking some minor points.

A certain manufacturer, who makes a circular cutter with long, delicate teeth curved and brought to a knife edge, heats all of them with this blow pipe brazing outfit, and claims to get better results than by any other way tried by himself or by others who had hardened some for him. He places each cutter between two disks of sheet steel about an inch larger in diameter than the circular cutter, with holes in them the same size as the one in the cutter. These are wired on securely and the flames from the two pipes meet in the hole formed by the three pieces so wired together. The piece to be hardened, when at the desired heat, is dipped into water with the shields still on, and then into oil to cool entirely. The temper is drawn to the desired point by hot oil with the guidance of a thermometer. These cutters are not used for cutting metals, but for hard wood, and they are run at a very high speed.

Of many methods of hardening steel little need be said, except that many have no place in shops where experience has taught that the best is the cheapest, and that the best steel needs no nostrums to improve it for tools, especially cutting tools. All good hardening is done on the basis mentioned above by all the leading manufacturers of fine tools for the market, the only difference

Cut No. 59.

Examples of good hardening and good steel. A large, solid steel roll, 12 inches in diameter, and a smaller one, both hardened hard enough to withstand a heavy blow from a ball pene hammer. Hardened by heating in a coal oven furnace and quenching in a large tub of running water.

lying in their possibly improved apparatus for producing the same results. For a good tool steel, economical to use for labor saving tools, nothing is needed except fair treatment with fire and water. Heating in red hot cyanide and cooling in sulphuric acid may be useful in hardening pieces where the greatest possible hardness is desired, but for tools in general it is worthless and very dangerous to accomplish.

Granulated bone, or bone charcoal, should never come in contact with any good steel intended for cutting tools, or stamping dies made from a steel worth using for expensive tools.

Hardening compounds, applied either to the steel in a powdered form or in the quenching bath, are also valueless to a good man provided with a good steel, a clean fire and plenty of fresh water. (See cut No. 59.)

RESTORING BURNT AND OVERHEATED STEEL, ETC.

CHAPTER VIII.

It is common among mechanics to call all overheated steel " burnt," and the remedies for restoring burnt steel are legion; but burnt steel that is really burnt cannot be restored. Overheated steel can be partly or nearly restored to its original working quality, but not entirely so, the extent of the restoring depending on how badly it is overheated.

This restoring can be done in two ways, neither of which requires the aid of chemicals. The best way of the two, unfortunately, cannot always be applied, as it consists of carefully reforging at right heats and with a proper hammer, and in the case of small pieces using good judgment about the weight of blows given. If the smith is careful he can restore the steel to a point nearly as good as it was when received. Of course, this way cannot be applied to finished tools like taps, reamers, etc., etc., which are more apt to be burnt than tools that can be forged.

The other way, therefore, becomes of the most importance and is as follows: When from any cause you find the heat on a finished piece has got beyond the proper hardening point, or, in other words, is overheated to any degree, withdraw it from the fire at once and plunge it into the annealing box to cool off slowly. After it is cold reheat at a lower heat and repeat the operation; when cool the second time heat to the right hardening heat and

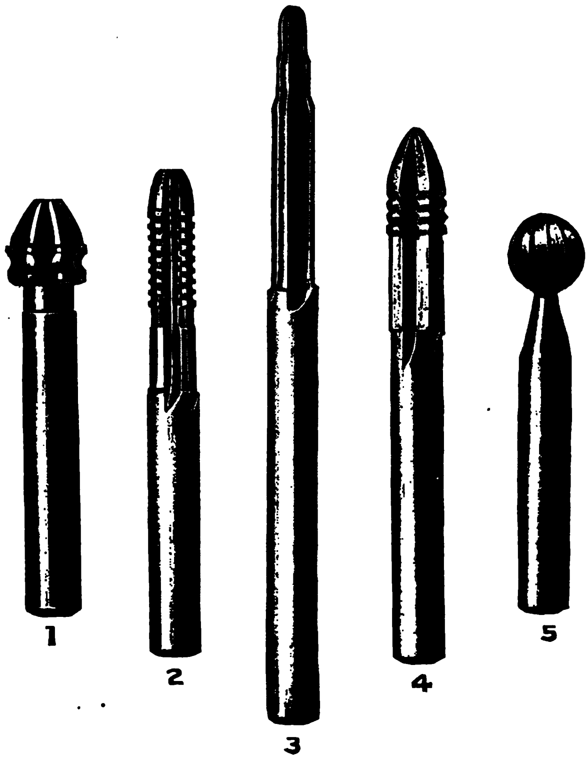
harden as usual. If the piece is badly overheated—that is, many shades above the proper hardening heat, in the second annealing substitute powdered charcoal for the ashes of the annealing box, or make a bed in the ashes of the box of the charcoal and cover the piece first with charcoal, and then over this cover the ashes and allow it to get entirely cold. Repeat this, if overheated nearly to the burning or melting point, and then proceed as originally intended.

In hardening tools in an open fire you will often air burn a tool without being aware of it in the slightest degree. This particular burn is one that has caused more trouble a thousandfold than overheating, and, with uneven heating, is the twin mischief maker among tool smiths and trouble maker for the steel manufacturers. Many a costly tool has been wholly or partly ruined by air burns, and many a good steel has been condemned because it would not do good work after being air burnt. Taps, reamers and all tools with a thin section for their working part are most liable to meet with this trouble when hardened in an open fire, or in any place where they are likely to receive a strong current of air when hot. The open fire of an ordinary forge is the most likely place where this knock out blow can be administered, owing to the readiness with which the fuel burns out between the tool being heated and the tuyere supplying the blast of air.

If the air from the tuyere strikes the steel after it has reached a red heat the trouble begins, and if continued the piece is ruined beyond any restoration. A tap made from the best steel known, subjected to this blast of air after it nears the proper heat for hardening, fails to hold a good cutting edge, the points of the teeth crumble eas-

ily, and if broken, show no strength, but instead a dry, brittle fracture.

The smith who is compelled to harden taps, reamers, threading dies and all other tools with a fine cutting edge



Cut No. 60.

Set of tools used in making cartridge reloading tools; No. 1, cherry for forming bullet mold; Nos. 2, 4, 5 for same use in other patterned bullets; No. 3, chamber reamer for making the chamber in the reloading tool. Cost of steel about 75 cents, cost of labor about $75. Must be very accurate and high-class tool making. Hardened in an open fire.

in an open fire cannot be too careful about seeing that he has plenty of fuel between the tuyere and his work, as steel air burnt is irrevocably ruined if thoroughly done. (See cut No. 60.) One of the drawbacks about this air burning is the fact that it can occur without being detected when being done, or changing the external appearance of the piece, either when hot or after quenching. For this reason the smith will insist that he had the proper heat, and will show you the heat at which he hardened the particular tool complained of, and you must admit that it is apparently the right heat, and conclude that the steel is not what it was represented to be. Consequently the maker of the steel often loses a customer.

These air burns are impossible when the piece is heated in hot lead or in a muffle furnace. If neither of these are at the service of the smith who has to harden the tools, but, on the contrary, his only resource is the open fire of the forge, he should resort to methods which tend to make this air burning impossible. This is best accomplished by building a heavy fire well banked up and inserting a short piece of good sized pipe closed up at one end, and putting in this pipe a small portion of pulverized charcoal. Also, secure a fire brick to lie in front of the open end, when needed to retain the heat. In case the work is of such a nature that it does not fit well in a piece of pipe, bend up a piece of sheet iron into a box with bottom, top and sides and one open end for inserting the work, and bring the fire brick into service as with the pipe. This will provide you with a round or square muffle, as the shape and size of your work may require. Any finished piece that is too large to be hardened in one of these makeshift ovens simply should not be attempted in an open fire at all. Many more tools have been lost

by uneven heating than by overheating, and good steel will crack much quicker from an uneven heat than from overheating.

Another piece is that a piece with a thin part and a thick part will look as though it was heated evenly, when the thin part is really much hotter than the heavier part, simply because the smaller body does not show the heat so plainly. When possible to do so the heat should be applied to the heavy part before the lighter part, and then, when both parts are apparently at the right heat, the thicker part should be dipped first to prevent the uneven strains.

It is a nice piece of work that the writer would not like to undertake to harden a large milling cutter in an open fire, even if it was of the plainest shape used. While this is accomplished every day by smiths who have no other means of heating at their command, it is the belief of the writer that in no case is the cutter as good as it would have been if hardened by heating in an oven furnace of some sort, where an even heat was easy to obtain. The writer has stood by and watched the smith heat and harden a formed milling cutter with a 6-inch diameter at one end, which curved down to a 4-inch diameter in the center, terminating with a square shoulder, from which began another upward curve, terminating at the other end with a 5-inch diameter with a length of 6½ inches over all. This cutter was apparently hardened at every point without showing any signs of a crack on the corners of the teeth or any spots that a file would touch more readily than others. The temper was drawn to the first suspicion of a straw color. It was then ground and put to work milling soft steel drop forgings. It worked as good as any they had tried, so they reported, but when

it was worn dull the writer examined it and found that the teeth in some places showed evidence of much more wear than in others, and were rubbed off much more. There were several of these places so distributed that they could not be laid to the driving arbor running out of true, thereby making the teeth on one side do more than their share. To make doubly sure that this was not the cause of the uneven wearing the writer stood by while the cutter was reground perfectly true, and readjusted on the driving arbor, and then made sure that the edge of every tooth ran in the same circle, by bringing the work up against the cutter just enough to allow it to cut its profile into the piece. It was found that every tooth touched when no feed was on. In a short time after starting we were able to hear the peculiar growl and squeal made by one tooth cutting more than its fellow, and after running awhile the teeth showed the same appearance as before grinding.

For an explanation of this we returned to the blacksmith's shop, where the smith was hardening another cutter of the same shape and size. On the way we casually remarked to the superintendent that the firm should have a better way of heating those large cutters than an open forge. He replied that as they had a smith that could harden anything in the open forge they did not think it necessary to go to that expense. When we reached the forge we found the cutter was getting red hot in some places and the smith was turning it in the fire so that the heat would strike the cooler parts more. After a few moments he turned it again and we noticed that some of the teeth were fully hot enough to harden on the side most exposed to the center of the fire, while the main body of the cutter was hardly a dull red. He continued to turn

the cutter until, after heating the teeth in several places fully as hot as they should be several times, the main body of the cutter had got hot enough to suit the smith, who then trimmed his fire so that the piece would be well surrounded with hot coals, and shut off the blasts to allow the heat to even up. This accomplished to his satisfaction he pulled it out and dipped it in a large tub of brine with a slow circular motion and shortly pulled it out with the solid steel between the mandril hole and the teeth, glowing a dull red, and quickly immersed it in a tank of oil. We waited until it was cold, and then when he withdrew it and having washed off the oil in soda water, we inspected it with a magnifying glass for cracks and tested it for hardness with a file. This done the superintendent pronounced all right and bestowed a compliment on the smith, which helped to confirm his opinion of his own extraordinary abilities and showed the continued confidence of the superintendent.

A subsequent visit to this firm disclosed the fact, on inquiry from the man in charge of the milling machines, that this cutter worked just the same as the other and "seemed to have soft spots in it that did not wear as well as the rest of the cutter." If you should have told the superintendent that the smith burnt out some of the wearing qualities of the steel in the places heated hot so often in getting the right heat, he would doubt you; yet this is just what he did. If you should volunteer to take one of these cutters made from the same bar, elsewhere, and have it hardened in an oven furnace, and you did so, returning it ready for use, and when put to work it was found that it wore evenly all the way round with no perceptible difference in any of the teeth, and it ran about three times as long without getting dull, the chances are

ten to one that he would credit it all to the fact that the temper was drawn in hot oil with a thermometer, and it doubtless got a more even heat in drawing the temper than was possible by their method. But as they were getting very good results it was not "worth while to go to the expense of one of those outfits, as it might offend the smith, who certainly made them hard enough in the hardening." So much for this kind of a burn, which is more or less common and which costs thousands of dollars each year for extra steel, extra tool-making and extra grinding, etc., etc. There are others, but the instances stated will serve.

EXPANSION AND CONTRACTION OF STEEL.

CHAPTER IX.

Good uniform steel will expand and contract the same under like conditions, while cheap un-uniform steel will vary so in its expansion and contraction that it is a hard matter for the tool maker to figure on how much to allow for such contingencies. Steel when heated hot is expanded to its limit, and when properly hardened and refined is contracted to its lowest limit. Steel properly annealed is at a medium between the two points of expansion and contraction if of the right quality and the proper temper to produce this result.

Medium hard steel contracts more in hardening than mild steel, it is claimed, but does not expand so much in annealing. Take, for instance, steel of a temper suitable for making taps. If this is annealed soft, as the average tool maker likes it, and the tap is finished ready for hardening in this state of softness, it will contract enough to change the lead to such an extent that a nut tapped with it could not be screwed on to a bolt cut in the same lathe at the same lead as the tap was cut. To avoid this trouble rough out the tap to nearly the correct size, and spline it nicely, then heat it to the proper hardening heat in hot lead and harden it in water. Polish it up enough to show the color, then draw the temper to a dark blue and chase it to your standard size, using turpentine as a cutting lubricant. Then harden and temper in the regular way and you will find that you have eliminated the greater part of the contraction.

Should you have a piece containing several holes which must retain an exact distance from each other, shape the piece ready for making the holes and do all the work on the piece that can be done outside of the very particular parts, then heat the piece to a low red heat and plunge it into water long enough to cool the outside. If it files on the outer corners allow it to cool in the water. If not soft enough to cut with a file, lay it in a dry place to cool slowly after having chilled it to this point. When it is warmed up from the interior heat so that it can be filed on the corners with a hard file, cool it off and drill your holes with turpentine as a lubricant or cooler for the edge of your drill. Finish the holes with all possible care, being willing to take more time for the sake of having them right; harden with the holes perpendicular over a force of fresh water, or by moving the piece up and down quickly enough to force the water through the holes until they cool below the steam generating point.

Should you be making a round drawing die, in which you do not want to have the hole shrink any, heat and immerse the whole die in still water with a circular motion. Should you desire to shrink the hole a little only, have a stream of running water under the surface of the bath, and, with the whole die immersed, place it so the stream will flow through the hole. Should you desire to shrink the hole as much as possible, place the hole on the end of a pipe of the right size and turn on full strength of the water until the die turns black nearly to the outside diameter, then immerse in oil to cool entirely off. Steel of certain tempers shrinks much better than others, and a steel for dies that are to be shrunk repeatedly when the hole becomes worn should be considerably higher in

temper than ordinary stamping die steel, and at the same time below what is best for lathe tools, etc.

It is one of the singular things that steel made from certain irons of Swedish production shrink much better and more times than any other known, also that these show a marked difference between the various ways of making them into steel. These irons when converted into blister bars and remelted into cast steel show this quality in a marked degree over the same irons converted in the melting process. The reason of this is a puzzle for which none of the steel makers offer an explanation.

Steel that expands in diameter in hardening should be discarded for fine tools, especially cutting tools such as taps, reamers, etc., as the edge is apt to be of little durability. Some grades of steel will contract lengthwise in hardening, while they have not changed in diameter at all apparently; others will contract both in diameter and laterally.

The steel that is freest from all foreign substances except carbon seems to be the most exmpt from these faults of uncertainty, excepting, of course, the high alloy steels, which change very little either lengthwise or in their diameter. Some of these high alloy steels have been known to change so little that it was impossible to detect any change with such measuring instruments as were in use in the shops where the observation was made, and hob taps made from these steels have been found to fit a sizing die perfectly after hardening that was run over it before hardening. The advantage of this high alloy steel for such purposes as hob taps and other tools, where it is important that no change take place in the hardening, and for such tools as may be safely made from this kind of steel, can be readily appreciated by tool makers who have

wrestled with the problem of making fine hob taps, etc. Another point we have to contend with in this matter of expansion and contraction of steel is the effect that it has on irregular shapes in regard to cracking them.

Take a ring shaped piece with a thick side and a thin side opposite, both of which have to be hardened as hard as possible. If the ring tapers gradually on both sides from the thick part down to the thin part, the problem is simple, but when half the ring is one inch thick and drops off with a square shoulder to one-quarter inch thick, and this shoulder having a square corner, you have a problem that sets you pondering how to get this glass hard at every point without cracking it in one of the corners of the shoulders. It will not do to dip the thick part first and remove the extra amount of heat that it contains over the thin part, or there will be a nice water check at the corner of the shoulder. If it is dipped over the shoulder the contraction ceases in the thin part before it does in the thicker, and the sharp corner becomes the point where they part company. The best way to get over the difficulty is to do away with the sharp corner of the shoulder temporarily until the hardening is done, and substitute a liberal fillet in making the piece, which is much easier to grind out into a sharp corner than to overcome the danger of cracking from the varying contraction.

You have noted former remarks about these sharp corners as starting points for cracks, but perhaps the fact may not have occurred to you that they are usually the dividing line between two different speeds of contraction, and that it is the extra strain at this corner that does the mischief with its fine line as a starting point for the crack.

Oblong cutting dies with oval shaped openings have a tendency to close in on the sides where the steel is light

in section in comparison with the heavier portion on the ends. This contracting can be overcome to a large extent by dipping one end slightly and quickly reversing the piece and lowering it slowly until the thinner part is reached, then immersing quickly, allowing it to rest flatwise on some level surface beneath the water. Of course, some judgment is required about getting the right heat when the dies are dipped this way, and the first end dipped should not be put in far enough to chill any part of the cutting edge, nor left long enough to chill the body of the steel in the immediate vicinity of the edge. Judicious application of the heat used in drawing the temper will remedy many of these troubles from contracting in hardening. The instances cited above will serve to show the main part of the trouble that the tool maker has on this score, and shows the best way of overcoming the difficulty—to wit, working the steel as hard as possible to work it in putting on the finishing touches. Of course, many instances may be given where the tool maker has this trouble to contend with, but the above will serve the purpose.

Another point that it may not be amiss to mention is that steel often contracts badly in plain, straight pieces on one side, with no visible excuse for doing so, in spite of the best possible treatment on the part of the smith This is caused by the steel being improperly, or carelessly, worked by the steel maker, or by the bar having been bent and straightened cold.

This warping sometimes spoils tools on which considerable labor has been spent, and is to be avoided whenever possible. (See cut No. 61.) The plan of heating a piece and hardening it before finishing to the desired size will always show if this cause of contraction is in

the steel, and will make it possible to provide against it in the final hardening. The act of drawing the temper so that the piece can be worked need not make any change in the warped appearance.

Cut No. 61.

A difficult pair of pieces to harden, having numerous sharp corners. Is a quarter section of a circle, is hardened all over and the temper drawn to the first symptom of a blue color. The two pieces are used together and ground to a knife edge for cutting the chime in beer barrels. Heated in a gas oven furnace. If warped in hardening would be spoilt.

Pieces are also warped or sprung badly by improper handling when in the hardening bath, such as moving the piece so that one side gets all the pressure of the cold

bath, and the other side is receding from it. In this case the workman must blame himself and not the steel maker.

Large dies will contract on one side and warp out of shape over a large stream of water necessary to use at times, to insure the best results in hardness, if considerable judgment is not used.

WORKING OVER TOOLS AND WORN OUT TOOLS, ETC.

CHAPTER X.

It is often asked of the steel salesman, "Will your steel stand working over as often as the steel we are now using," etc. The answer to this question depends upon what sort of a tool the steel is to be made into in the first instance. The writer has known a firm to work over square threading dies seven and eight times and get (to them) satisfactory results. By making an analysis of the chips taken when the die was first made, and the filings taken from the die when it was pronounced worn out, it was found that the steel had lost eighteen points in carbon in the repeated annealings and rehardenings. A piece of higher carbon steel was tried in this place, made especially for these dies, and it was found that while it stood working over several times, it did not give nearly as satisfactory results the second or third time as it did the first time, and although the die cut more pieces in the first hardening than the other did in the eight times reworking, the steel was condemned because it would not stand working over as many times as the other, which cost over twice as much to start with.

If you desire a steel that can be repeatedly reworked in threading dies, reamers and milling cutters, confine your purchases for this purpose to the highest grades of comparatively mild carbon steels made from blister steel, or as near a combination of pure iron and carbon as can be produced, avoiding all high carbon and alloy steels. But

if you care only for the amount of work than can be produced with each piece of steel made into a tool, a comparison of the results obtained between the steel that can be worked over and the steel made for you by a reputable steel maker especially for the purpose will show that the latter is the cheapest to use. These oft worked over dies were square in shape in the start, but when discarded they resembled a Maltese cross from the repeated setting in while hot on its four sides to secure stock for the repeated retapping. The last two or three times they were redressed they hardly did work enough to pay for the trouble of doing it, but then every time counted on the record.

Lathe, planer, shaper and kindred tools that are reforged every time they are renewed should not deteriorate perceptibly if properly dressed and hardened in each instance. But if the tool is heated far above its working point and repeatedly hardened further up than it is necessary the steel will not do as well in the subsequent redressings as it did in the first instance, nor will it do much more than half what it should do in the first forging, because it is probable that in heating the piece hot in the larger section the smith has heated the working part of the tool beyond the heat required for it to be at its best. Hand cold chisels can be worked until too short for further service, if properly forged and hardened with some judgment regarding the service they are to be put to. Large cold chisels, such as are used for cutting rails and heavy sections of steel and iron, are apt to deteriorate and become brittle and easy to break after repeated redressing, even when the utmost care is used in forging and in the hardening, owing to the severe blows they are required to stand in use. These chisels, if properly made,

should not need redresssing often and really should wear out their head in one dressing if properly used, provided care is taken not to strike foul and on to material not fit to cut with them. This somewhat broad statement may be made in regard to all the tools used under sledges in blacksmith and boiler shops, such as flatters, fullers, setts, swedges, etc., etc. The writer has seen a cold chisel made of 1⅜ inches square steel used in a blacksmith shop for cutting cold steel and iron for over three years without redressing. In this time the head had worn down by flaking off under the blows of the sledge until it has worn down to the center of the handle eye, and when the handle would no longer stay in the worn down hole a withe was bent around the bit and its life prolonged in this way. The blacksmith who made this chisel is of the opinion that he accidentally got hold of an exceptional piece of steel in a bar that got touched just right at the particular spot that this chisel came out of, and he is equally sure that the rest of the bar was not the same as this particular piece. The bar was the same all through, but the smith's work on the remainder was not the same as on this chisel, which he happened to forge and harden just right. The steel that this chisel was made from was an American steel costing fourteen cents per pound.

One kind of hardened steel tool that it does not pay to work over is the engraved stamping dies such as are used by silversmiths and manufacturing jewelers. The blows that these dies are subjected to have a tendency to strain the steel below the hardened outer surface and pack it together, so to speak, in a manner unnatural to itself, the result of this being the steel loses some of its tenacity and strength, and in the processes of reannealing, reworking and rehardening cracks are liable to show either

in the hardening or soon after the die is put in work. As the reworking of these dies costs many times what the piece of steel costs to make a new one the folly of attempting to work over one of these dies is plainly apparent.

Hobbed dies will invariably crack in the second hardening, and while discussing this subject the writer wishes to remark that the cold hobbing of dies for severe work has not proved a success owing to this cracking objection which is the result of undue packing together of the steel in such a manner that it cannot resume its natural position in the hardening process.

The foreman in a large silver shop once told the writer that he fully expected the cold hobbed dies to crack; but as he had the hob, if the die broke in hardening he could drive another. These shops that are partial to hobbing are always good customers for steel makers. Another superintendent of one of the most successful silver ware manufacturers in the world, who make a line of sterling silver and heavy plated ware, plated on twenty per cent. nickel German silver, told the writer that he had had so much trouble with hobbed dies breaking in hardening and giving out in use that he had abandoned cold hobbing for fine work and had the dies engraved entirely that he was the most particular about. He also imparted the information that he found that it did not pay to work over old stamping dies, even in the plainest patterns, but that he did work over trimming and blanking dies with good results.

Milling cutters may be worked over and over until their diameter gets too small for further use, if proper care is used in each hardening, and their working quality will depreciate less than any other tool except improperly forged ones.

It is the custom in some shops to make a large die for making drop forgings and place the same in a drop and strike up a few pieces to make sure that the die is right before hardening, and then blame the steel maker for giving them poor die blocks if the die breaks in hardening or gives out quickly in working, as the largest percentage will do. And when one of these dies stands up fairly well until it is worn out it is reserved from the scrap heap for working over. As a preliminary step it is annealed and laid on one side until wanted. When the time comes that a block of its size is required it is brought forth and the die sinker proceeds to sink another impression by first removing as much as necessary from the face by planing it off. This done, he takes it to his bench and proceeds to lay out the design wanted on the new surface. In doing so he notes numerous small checks all around the outlines of the old impression. As he gets to work cutting the new impression he finds that these are not confined to the upper surface of the die, but that the steel under the part covered by the old impression is full of them. The amount of service that the die did in the first instance is not considered, or the amount of abuse it had to stand in order that these numerous spots should be there. The die sinker calls the superintendent and the steel is voted by both of them no good, as it is full of flaws—that is, no good for working over.

It may not be out of place to mention the tools used in drilling oil wells as fair samples of worked over tools. When the oil industry first started the drillers went to the steel makers and said they wanted the best thing possible for drills and were willing to pay for it. Steel costing fourteen cents base was furnished them, made from the best Swedish iron obtainable. The bits were made

and shipped to the oil fields, hardened and tempered ready for use. Arriving there they were put in use and used until they became dull, then were hauled up and unscrewed from the driver or jars, as the case might be, and replaced with others. After the tools were started again the driller and his helper proceeded to resharpen the dull bit. It may be well to say right here that these bits ran in size from six to ten inches in width by two to five inches in thickness, and the bit with its shank was about all two men could handle in the larger sizes. For this sharpening they were usually provided with a portable forge inside, or near, the derrick. This forge was generally of the right capacity for heating boiler rivets properly and sometimes large enough for properly heating a cold chisel. The bit was lifted up so that the end rested in the fire, and as much coal as the forge would ignite, and often more, was heaped around the end of the bit, and by dint of vigorous blowing from the bellows on the part of both men the edge was pronounced hot enough for drawing out. When the bit was withdrawn from the fire and laid on the anvil you could count as many shades of heat as Joseph is reputed to have had colors in his coat, yet the drawing out immediately began with heavy blows from a twelve-pound sledge, any part not being hot enough to draw being the point of extra attention in the next heat. By dint of several heatings and with the aid of a hot chisel to cut off the lumps that appeared from the drawing out process it was shaped. When trimmed up to their satisfaction it was again returned to the fire for the crowning operation of all, the hardening. One corner might get too hot and was moved over until the other was in the same shape. By this time the first one was partly cooled off and was again moved to the hottest part of the fire. As

it was partly hot they gained a little on the other, and when ready for the next move it did not have a chance to cool so much before the other got hot again. Back and forth it was moved until both the corners were hot enough to suit them, then they moved the center of the bit over the hottest part of the fire and heated that as quickly as possible before the corners got cold. When this was accomplished the bit was quickly pulled from the fire and plunged into a tub of water standing near. No time was usually wasted in tempering unless one of the corners or the center happened to be so hot that they had misgivings about it standing. In this case the heat was applied to the point in question with an idea that it would undo the mischief. Consider the sense of using a high grade of steel and treating it in this manner!

Another steel maker took a trip of observation through the oil fields and saw the way the steel was treated and the grade of steel being used. He immediately offered to supply a steel that "would do just as well" for about half what they were paying, and did so. Still another viewed the operation and noted the steel used and the treatment it got. He concluded that he could furnish a steel that would do just as well as either for a little more than half what this last or cheaper cost. He did so, and to-day cheap steel holds the bulk of the business. This last steel was open hearth steel, and it will do as well, and in all probability better, than the best with the treatment given.

It will be seen from the above that we have the working over question in another phase here, and also that the cheapest and poorest of the three was equal to or better than the best when subjected to this working over treatment. What would have resulted had the best quality had proper treatment is another story.

One might continue indefinitely recounting instances where the steel maker has been blamed for the sins of the mechanic, who applied his own peculiar methods with disastrous results, the greater part of which he will always lay at the door of the steel maker, with no thought of blaming himself. To attempt to show them where the fault lies means usually to make an enemy of the man and often results in the loss of a customer. Nothing but the mildness of the steel required for these tools and for drop and stamping dies prevents them from breaking into many pieces in the hardening under the usage mentioned above. The steel maker has trouble enough to furnish good sound steel at a fair price, without being blamed for defects made by poor workmanship after the steel has left his hands.

GRINDING CUTTING TOOLS.

CHAPTER XI.

The question of the best method to employ in grinding shop tools is one that has been much debated and in some quarters remains still unsettled.

The advent of self-hardening steel brought the dry emery wheel into extensive use, as the statement was made that grinding could be done on a dry wheel and the tool be heated red hot without injuring the cutting qualities. The natural tendency of mechanics is to investigate these points; besides this, they seemed to prefer grinding on a dry emery wheel to a wet stone. The natural result was that in a short time they were grinding all kinds of tools on the emery wheel, whether made of the self-hardening steel or not. This, of course, resulted in drawing the temper on the tools made of ordinary steel to such an extent as to nearly spoil them so far as their ability to hold a hard, durable or fine edge was concerned. To overcome this, as the men disliked the slow cutting grindstone, a large variety of grinding machines were evolved, which were fitted up to use water on emery wheels. This overcame the difficulty to a certain extent, but not entirely, as it was found that many of the emery wheels had the fault of starting the temper of the tools even when plenty of water was used, if the tool was forced hard enough against the wheel by a man in a hurry to get through the grinding. Nevertheless, the water emery grinder was considered by some the acme of all grinding apparatus, until the extensive use of high alloy steels in

the leading shops convinced them that they needed a grindstone to get the best results. The new high speed steels did still more to convince them on this point, as the directions furnished with most of these steels required that they be ground on a grindstone preferably to secure the best results, and made it imperative that they should be at least ground on a wet, fine, free cutting wheel to secure the results claimed for them when the grindstone was not available.

But putting the self-hardening and alloy steels out of the question and returning to the ordinary steel that is used for a thousand and one purposes that the alloy steels and the self-hardening steels are not as yet adapted for, we are forced to the conclusion that for fine edged cutting tools nothing equals a fine, free cutting grindstone. The reason of this is plain if we examine closely the edges of the tools ground respectively on a grindstone and a wet emery wheel. Under a magnifying glass the edge of the tool ground on the emery wheel shows coarse teeth, while the one ground on the grindstone are very much finer. For an exaggerated comparison compare the teeth of a coarse toothed cross-cut saw with those of a carpenter's miter-box saw. Still closer examination shows that these coarse teeth are irregular in shape and that instead of having an edge formed by an angle of eighty-five degrees or less, as desired, we find that the sharp point of the angle forming the edge is broken or rubbed off by the wheel in the process of grinding, and that the friction has been so great that the temper is started on the fine extreme edge, if any such happens to remain. In short, grinding on emery wheels will never produce an edge to compare with the one produced by the grindstones for wear or for cutting qualities, etc.

The writer has stood by and seen a man heat the edge of the tool to a red heat under a stream of water running over it from the wheel by bearing on so hard that none—at least, not enough—of the water got between the tool and the wheel to counteract the high friction made by the hard pressure at which the tool was held against the fast revolving wheel.

If you desire the most rapid and economical outfit in the emery wheel line for grinding tools used in a machine shop, or in localities where similar tools are used, there is a grinding machine on the market that overcomes the major part of the above objections. The reason it does is that the tool is fastened into a holder which is adjustable at any angle, and this holder in turn is secured to a movable part of the machine susceptible of being moved in all directions required at the will of the operator. When the tool has been firmly secured in this holder and the holder has been adjusted at the angle desired it is brought up against the face of the wheel, and the operator moves it up and down by a lever which gives the tool a vertical motion, enabling the wheel to cut new surface all the time. It does not heat one spot continually until the temper is drawn. The screw feed attachment allows the operator to adjust the amount being ground off to suit him, and the liberal sized stream of water projected from an adjustable nozzle directly onto the tool and wheel where the cutting is being done, combined with the constant vertical movement of the tool, prevents heat enough being generated to start the temper on the vital point of the tool—*i.e.*, its cutting edge. By this method of grinding a broad nosed cutting down tool can be ground with a clearance of any number of degrees desired, and when one part is done the holder can be adjusted to give any

desired shear to the top. It can then be again adjusted to give the desired clearance on the sides without removing the tool from the holder, or *vice versa*. For expeditious grinding of large planer and lathe tools this grinder is far ahead of anything known, and a large shop equipped with one of these grinders in their tool room, with a man in charge who will take the pains to touch up the edge a little on a fine, wet grindstone, or by honing with an oil stone, will find that they have the best money saver known.

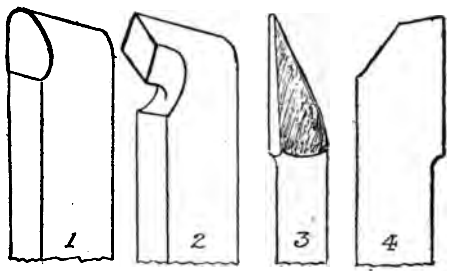
Until recently all milling cutters, reamers, arbors and parts finished by grinding after hardening and tempering have been ground on machines using dry wheels. Observing mechanics noticed that if the operation was hurried the color started on the teeth of the reamers and milling cutters, and the extreme points of the threads of taps were found to be soft from the slight grinding they received in facing. Soft spots were found on arbors that had been hardened glass hard, parts of hard, circular cams wore out and required replacing much sooner than they should have done. The cause was looked up and found to be the dry grinding done after the piece was hardened.

The desire to rush work without spoiling it, and the fact that dry grinding was found to start the temper on all fine edges resulted in a variety of wet grinders being invented, so that it is now possible to wet grind almost any sort of a tool or piece without starting the temper, and shops equipped with these grinders have a great advantage over those which are not.

We once observed a case that will serve to illustrate this grinding of common, forged shop tools. A sample tool was brought to a certain firm made from one of the

new high speed steels with the request that they test it. The tool in question was an ordinary round nosed tool, ground with five degrees clearance and about ten degrees shear on a wet grindstone. This tool was taken into the shop and given to one of the best men, who, after testing it thoroughly, reported it the best tool he ever had hold of in his shop experience, and requested that some of the steel be ordered for his use. This was done, and as soon as the bars came he had the smith make him some tools from it according to his notions of the proper shape, etc. After the tools were made and hardened according to the directions furnished with the steel, he ground them up and tested them. It did not take him long to arrive at the verdict that the steel sent on his firm's order was different from what the sample tool was made from, and such was the report that went to the office. A complaint was made to the firm furnishing the steel, and their men called to see where the trouble lay. He found the man fully convinced that the steel furnished was not like the sample tool, as it would not do one-twentieth part of the work that the sample tool did. The new tools were called for, and when they were shown it was found that, instead of being round nosed, they were a cross between a side tool and half diamond point, which was the favorite shape with this man, as he could turn closer to a shoulder than with a round nosed tool. (See cut No. 62.) One of these tools was taken to the blacksmith's shop and forged into the same shape as the sample tool, hardened and ground and found to do as much work as the sample tool. It will be observed from Fig. 62 that such a tool as is described as failing has a perfectly flat surface from heel to point, and that a very small amount of stock is left at the point. In grinding this tool it must be held against

the wheel continuously on this flat surface until the required amount of grinding is done. This generates sufficient heat to start the temper on the edge enough to do mischief, though not enough to show any color, as the color is ground off. It will also be observed that the small amount of steel at the point of the tool does not offer sufficient resistance to the heat naturally generated in working at a high speed.



Cut No. 62.

The right and wrong shaped tools to use for rough and rapid work when made of high speed steels: No. 1 shows the best shaped tool for hard, rapid turning. Note the large amount of stock left as a backing for the part doing the work. No. 2 is the next best shaped tool for rough, rapid work. Nos. 3 and 4 show two views of a shaped tool that some mechanics try to make do the work that is done with No. 1.

A continuation of this test with the round nosed tool under the proper conditions and with the other shape as formerly used showed that the round nosed tool in this particular sort of work would do over five hundred times as much as the other before becoming dull. This may seem an exaggerated statement, but it is the actual fact and can be verified. In fact, the round nosed tool in the final test turned one hundred and twenty-six pieces nine inches long at a speed that made the other give out in run-

ning one and one-quarter inches. Figure it up for yourself.

The shape of the tools and the method of grinding are jointly responsible for the result cited. It will be noticed that in grinding a round nosed tool it is necessary to keep the tool moving in a circle; this prevents the wheel bearing long enough at one point to generate sufficient heat to soften the extreme edge. It is a waste of time and money to buy high priced, high alloy or high speed steel for tools, and then reduce their wearing capacity far below what should be expected from ordinary steel by careless and antiquated methods of edging them. One manufacturer will say " So-and-so is using a steel that costs about three times what we pay. We tried it and did not find it any better than the ordinary, or at least not enough so to interest us." The reason of this can always be found in either the blacksmith's shop or at the grinder.

There can be no question about the economy of using high alloy steel for nearly all lathe, planer and kindred tools, and to secure the benefits of this economy the proper treatment must be accorded to the steel from start to finish, and any extra time spent in making or grinding will pay large dividends in time saved and extra work done.

One more point about grinding with dry wheels should perhaps be mentioned here. It refers to surfacing off cutting dies that have become dull to produce a new sharp cutting edge. Dies ground off on the top with a dry wheel will be found to have a thin, soft skin spread over the entire surface so ground. The fine edge will also be found to be soft at its extreme point to a more or less extent, according to the amount ground off and the care used in grinding it. The writer has seen dies ground so that one could take a hard, fine file and file enough off

the edge before reaching the proper hardness so that it was below what it was when taken out of the press to be sharpened. Of course, as this is the vital point of the die, it soon becomes dull again. Grinding machines are made that permit of the die being entirely under water when being ground, and thus preventing the drawing of the temper at all.

This question of grinding tools and parts properly is one that has not received the attention that it merits. Many shops that intend to keep up with the times in all labor saving appliances and who supply their men with the best steel obtainable, and who have all the latest and best hardening appliances, will permit their men to sacrifice half of the life of the tools, carefully and skillfully made and hardened, by allowing them to grind them on dry emery wheels. It must be borne in mind that in grinding cutting tools with fine edges it is the fine edge that does the work nicely, and that it requires but a minute portion of soft steel on the extreme edge, hardly perceptible to the naked eye, to spoil this fine edge for all keen cutting.

SOME OMITTED POINTS ABOUT DECARBONIZED STEEL, ETC.

CHAPTER XII.

We find in looking over the MSS that in our anxiety to give practical illustrations of the case cited we have omitted some points that should be mentioned in order that all those points not covered by other writers may be mentioned herein.

One of the most important among these is the item about skinning steel too close to the outside in making tools from pieces cut from the bar without forging by the smith. This point of not turning off enough stock has resulted in making worthless many a tool after considerable money had been spent in shaping it, as well as making it necessary to work many others over after they had been all through the processes of shaping and hardening. The writer has seen twelve large milling cutters made from one bar, each costing to make about twenty-five dollars, all of which had to be worked over to the extent of recutting the teeth deeper after reannealing them, simply because it was found after hardening that each tooth had about one-eighth of an inch of soft metal on the edge that would not harden. This was caused by the makers selecting a bar that was too near the size of the cutters which they desired to make from it; so near that it did not permit of turning off enough to remove the decarbonized skin that exists to a more or less extent on every bar of steel under the black scale. On small sized bars this is not apt to be deep enough to be noticed if the steel is turned or

cleaned to any extent, but it can be detected on one inch bars if an attempt is made to harden a piece with the scale on. It will be found that the outside will file to a small extent before the hard surface underneath is reached. As the bars increase in size the depth of this decarbonized surface is found to increase, so much so that in many cases it requires a good heavy cut to remove it all to a certainty. Bars five inches in diameter have been known to have this soft steel envelope under the scale to the extent of one-quarter inch in depth. Of course this is an exceptional case and simply shows what may occur in some case when it is least expected.

We shall not attempt to say what is the cause of this decarbonized skin which exists underneath the scale of bars, as steel makers themselves differ on this point. Some claim that it is the action of the air on the red hot bar used to blow the scale off from the dies when the steel is being hammered, while others claim that it is done in the heating. Still others finally claim that the formation of the black oxide on the outer surface of the bar withdraws the carbon to a certain extent.

The main point to be considered is how to guard against it. This can only be done by removing enough stock from the outside to make sure of taking this decarbonized steel off, and to establish a rule that it is safe to be guided by, the plan should be followed of ordering the steel enough larger than the finished size, according to what the size is, allowing less on the smaller sizes and more on the larger ones. For instance, no allowance need be made at all on sizes below one inch, which are to be turned enough to clean them. From one inch up to two in diameter allow one-sixteenth, from two to three inches allow one-eighth, from three to four and one-half allow

one-quarter, from four and one-half to six inches allow three-eighths, and you should be able to feel sure. Of course it must not be understood that it is necessary to remove this on all bars. A hundred bars might be bought on which a part of this would be ample. Then again a hundred bars might be received which required all of this amount taken off. The main point is to be sure. It will also be well to bear in mind that to be sure even with this allowance the piece should run very nearly true, so that four-fifths of the allowance would not be taken from one side and one-fifth from the other.

Attention to these points is of utmost importance in making all such tools as require their working point on the outer diameter or surface of the bar, such as taps, reamers, broaches and milling cutters, etc. For solid threading dies, drawing dies, hollow mills, spring threading dies, etc., of course, this point is not of so much importance and would not have any importance if it were not for the fact that some of the steel for this purpose might be nearer the size that some tap was which had to be renewed than the size intended for making this particular tap.

This question of soft skin also makes trouble often on large, flat sizes which are used for cutting and stamping dies in cases where the die is planed up by just skinning the side that happens to be selected for the working part. An engraved stamping die with $769 worth of work, mostly in engraving, failed to harden at the vital point (the engraving) from not having had enough planed off to remove the decarbonized steel existing under the scale. An English maker of fine steel who prided himself on making his bars to the exact size that his orders called for lost some very desirable trade. His competitor fur-

nished steel enough larger than the size called for to enable the consumer to turn off enough to entirely remove the decarbonized skin in turning them to the same desired size as he turned the ones made to exact size in the bar, which left a portion of the soft steel on because so heavy a chip was not turned off.

Another point that deserves mention is the custom that some mechanics have of reannealing steel after they have received it annealed from the steel maker. This is a very bad practice and one which should be discouraged, as it puts the steel into such shape that it will not harden and refine as it should, and makes it of a nature similar to cheaply made steels which do not have the benefit of the same amount of working as the better grades.

It is also common to double anneal both hardening high alloy steels so that they can be worked as easily as regular annealed tool steel. If this is done with most of the highest priced high alloy steels the greater part of their wearing qualities is lost beyond recovery. Bath hardening alloy steels to be at their best should not be annealed at all, and most of them can be worked successfully by an experienced tool maker without annealing, but of course not so rapidly as ordinary annealed steel. The extra time spent will, however, be well invested, as it will be found if the experiment is tried. The steel in question is very close grained in its natural state as received from the maker, and for this reason should be expected to work considerably harder, and any annealing that will make it as soft as desired by some makers of tools will undo this fineness and perfect blending of the alloys with the iron and carbon to a great extent. This is one of the reasons that makes one consumer say: "We tried such and such a steel and could not get as much work out of it as we could

out of our regular tool steel, which does not cost us half as much," while his neighbor will say that he can get ten times as much out of it.

These points about decarbonized steel and over-annealing apply particularly to steel of high quality, and the most careful maker in the world cannot entirely overcome the former nor provide against the mischief worked by the latter.

One of the most successful makers of hardened steel rolls used for rolling hard brass wire, plated stock, German silver, sterling silver and other plate made it a rule to take off one-half an inch on all diameters above four inches.

One of the best mechanics that New England ever produced, as well as one of the leading inventors, made from unannealed bar steel as received from the mill all kinds of small tools, even bottle shaped gun reamers for shaping the cartridge chamber of guns, also taps, reamers, milling cutters, etc.

We mention this, not as a necessary proceeding, but to show what can be done if one tries. It may also interest the reader to know that he also made all his turning tools by milling them into shape from the unannealed steel as received, with the idea that no blacksmith could improve the work of the steel maker. This is carrying a notion to the extreme and probably further than there is any need for doing in regular shop practice.

HIGH SPEED STEELS, THEIR USE AND TREATMENT.

CHAPTER XIII.

Recent discoveries in making high alloy steels bid fair to completely revolutionize all methods and ideas previously employed for turning, planing and shaping steel and cast iron. Whether these new steels will ever prove economical for all these purposes remains to be disclosed. However, a machine shop that is not equipped with this steel for all roughing work on lathes and planers is being run at a disadvantage in comparison with one that is.

The limitations of these new steels are comparatively unknown at the present writing, but if the somewhat extravagant claims of some of the makers are to be relied on, we may expect to see ninety per cent. of the carbon steel makers shut up their mills and seek some other business, as well as see the proprietor of a machine shop equip his shop with small tools about once in a decade. Be this as it may, one point is settled beyond all dispute and which is, that for roughing tools used in a machine shop, this steel is the most economical to use, notwithstanding the high prices being charged for it at the present time.

From numerous brands offered on the market by nearly every steel maker of any importance it would appear that no great and profound secret exists about making it and that the material required is easy to obtain. Up to the present time there seems to be no disposition on the

part of any maker to cut the fancy prices being charged for it, and as the expense of introducing it into shops and seeing that it gets the radically different treatment required for it is great, it is doubtful if any large profits are being made. This will probably continue until some manufacturer discovers some way of making his steel superior to any of the others in such a manner that the others cannot approach him in quality. It is fancied by some that this steel is not economical for them to use because their shop is not equipped with machine tools strong enough to stand all that the steel is capable of. This is a mistake.

These steels are economical to use at ordinary speeds, such as the lathe, planer or machine may be capable of, from the standpoint of the time saved in grinding, re-forging, etc.

Of course, if the shop is equipped with tools capable of being driven to the limit of what steel will stand, you are more fortunate, and the use of this steel will yield a larger percentage of time and labor saved; but your competitor with the lighter machinery must still use the same steel to get as near as possible to the results obtained by you. If you are using the best and your machinery will stand the strain you should be able to reduce an ordinary good machinery steel shaft, half an inch in diameter, at a speed of seventy-five feet per minute, and take the same chip on the cast iron at a speed of one hundred and ten feet per minute. (See cut No. 63.)

If you have a powerful planer gibed so that its speed can be increased safely, you should be able to plane steel rails at thirty-five feet per minute without trouble, and cast iron at as high a speed as any ordinary planer can be made to run, providing you are using one of the best grades.

Cut No. 63.

Photograph two-fifths of actual size of a chip turned with one of the new high speed steels from an open hearth forging at a speed of 32 feet per minute.

Cut No. 64.

Chips of soft machinery steel turned 195 feet per minute with one of the new high speed steels, reduced one-half.

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The above mentioned lathe speeds are about the limit as far as is shown at present, and, of course, to obtain this speed the steel has to be reasonably soft and the cast iron, also. Chilled iron has been cut with these steels at a speed of thirty feet per minute, and car wheel tires have been turned at the highest speed that the wheel lathe was capable of with the back gear in. (See cut No. 64.)

The writer was recently shown a milling cutter of the proper shape for cutting the teeth in milling cutters which was being run at a speed of one hundred and fifty feet per minute, with oil as a lubricant, milling steel of 1.20 per cent. carbon, to the great satisfaction of the user.

Reamers for automatic machines made from one of these steels were yielding over one hundred per cent. more work than any others ever tried by standing a greatly increased speed, and lasting much longer as well.

Whether this steel can be produced in quantities sufficiently reliable and uniform for use in expensive tools is an open question, as is the one whether it has a large range of utility adapting it for the large variety of tools made from steel. One thing is plainly evident, it will not do for tools subjected to severe shocks and blows, neither will it serve for fine taps, threading dies and other fine tools with many small points, which would melt before their base got hot as required to harden properly.

The many tools requiring a certain degree of elasticity could not be satisfactorily made from these steels; in fact, their utility seems to be limited to those tools that can be safely used with all the hardness that can be put into them. What may be discovered in the future about a steel of this description that can be hardened

without melting the smaller parts out of shape, and which can be tempered to suit the work it may be required for, is what no man can safely predict. But we think that the bath hardening carbon and alloy steels will hold their place for many years yet, for most all tools requiring a considerable amount of skilled labor to shape them ready for hardening and where distortion in hardening ruins the tool.

The methods of treating these steels in the forging and hardening processes are nearly the same on all of them in the main principles, though some varying directions are given in each instance. The following may be considered a fair example of the essential points to be observed.

Heat the steel to a bright red heat, heating thoroughly through, by letting the tool soak after the outside reaches a bright red; then forge into the desired shape, reheating as often as required should the heat die out before the desired amount of forging is done. After the tool is forged into the shape desired return to the fire, taking care that a good body of fire is between the tuyere and the tool, so that none of the air strikes the tool during the heating. Heat the working part of the tool to a white heat, and if necessary to melt the point of the tool slightly, in order that the white heat may extend back as far as the tool is likely to be used, do so without fear of injuring the steel in the least, as it does the steel no harm, except that which is entirely melted. After heating as described above, place the tool in a blast of dry air, point toward the air, to cool entirely off. When cold grind on a wet wheel or grindstone, enough to thoroughly remove all scale and traces of heating from the working part.

For tools that have parts that may be spoiled by the high heating, melting or warping them out of shape, heat as hot as possible without injuring the parts in question, and when hot plunge the working part into a heavy oil, taking care that it is not dipped deeper than where the tool shows a bright red heat. After cooling the point in this way place the tool in an air blast to cool, as in the case above. Should you be making a tool that requires hardening all over heat as hot as possible without melting any part, and immerse all over in oil. (See cut No. 65.) Milling cutters and reamers are successfully hardened this way and very satisfactory results have been obtained.

The point about heating the piece evenly all over to a high heat must be observed, as the steel in question seems to have a tendency to crack when put in oil at any heat below bright red. For this reason it is best to heat and harden the shanks of reamers and other tools that require hardening in oil.

Tools that have been air hardened so that the point was stone cold to the touch have been removed from the air blast, while considerable heat remained in the large body of the tool, although not perceptible to the eye, and the tool placed in water to hurry it in cooling so that it could be handled. The amount of heat so remaining has caused the steel to crack and break several inches above where it was heated to a white heat.

Forged tools made from these steels and carefully ground on a grindstone or a wet emery wheel, and well honed with an oil stone, can be used with water for finishing with satisfactory results and run at a very high speed.

Some claim, however, that they can do much smoother work with the ordinary carbon steels and at

Cut No. 65.

Some of the tools being successfully made and oil hardened from the new high speed air hardening steel, and guaranteed to do ten times the work that the same tools made from ordinary steel would do. Whether this can be continued or not is one of the unsolved problems.

as high speed as they desire. Be this as it may, there is no doubt that this high speed steel is an important factor in machine shop practice, and that the machine tools will have to be strengthened and a wider range of speed and more powerful driving capacity employed to enable the manufacturer to derive the full benefits from this new kind of steel.

The idea of heating to a white heat is so foreign to the long established practice that considerable difficulty is experienced in getting smiths to treat the steel according to the directions furnished.

It has also brought the usual crop of humbugs and quacks, who claim to be able to convert common steel into similar steels, etc. These charlatans claim to supply with chemicals applied to an inferior base the qualities obtained by alloying expensive iron with the more expensive alloys. The fallacy of this claim is apparent to all. Yet it is the fact that these humbugs, who claim to produce results which cannot be attained by steel makers with all the experience of a lifetime, with their force of experienced men, their chemists and other sources of information, they find disciples, and these among mechanics of intelligence. Every new discovery that is made by those who are continually employed in scientific research results in a fresh crop of alchemists, each of whom seem to find people willing to part with their money for their worthless nostrums.

The extraordinary results obtained from these high speed steels are due to natural causes brought about by the combination of the various other minerals combined in proper proportion with good, pure iron. To secure the uniform results the same care is required as in making carbon steel, and in all probability more, as we have

more of an assortment of material to deal with. Before these steels can be used successfully for expensive tools this point of uniformity will have to be an accomplished fact and well maintained. If it can be done it will be a long stride toward shop economy. Whether it can be done time alone will tell. Meanwhile we must acknowledge that its circle of usefulness is limited.

A FEW BRIEFLY STATED FACTS.

CHAPTER XIV.

When it is a labor-saving steel that is required, the one that will save the most labor is certainly the cheapest to buy.

The man who knows all there is to learn about the steel business, or about what can be accomplished with steel, is not born yet.

The better the mechanic the more anxious is he to learn, and each passing week usually adds to his store.

Do not always think because a man is so unfortunate as to have to sell steel for a living that he is always ignorant of what he is talking about; wise men have learned from fools.

The man who may have had the best steel yesterday may have second or third best to-day; the world moves.

Certain facts are unchangeable; it takes good flour to make good bread, good iron to make good steel, and good men to do good work, all of which cost high.

Cheap steel is only suited to cheap men without ability to work good steel, who would get the same results from either.

To the investigators we owe all improvements; if all were content to continue in the path their father trod, where would we be?

Good mechanics utilize and take advantage of the forces that nature has placed in their hands; others seek to change them.

Why does steel harden? It all contains less carbon than cheap cast iron. We wait a lucid explanation.

Ten thousand needles tempered so near alike that no difference could be detected, and done all at once, is a good mark to work to.

A lathe tool running for seven days on cast iron at sixty-five feet per minute, ten hours per day, without grinding, and in good condition when the job was finished, is a fact which you are at liberty to doubt.

The ignorance of the steel workers have made many fortunes for steel manufacturers, and probably will make many more.

When mechanics learn to get out of steel all there is in it, the demand will be reduced by a large percentage.

Our most useful discoveries are accidents; if a careless blacksmith had not melted the end of a self-hardening steel tool, we should not have known about the "white heat."

A bar of steel that can be used for any kind of a tool is not much good for any of them.

"Red short" or "cold short" steel means poor steel and a waste of time and money if made into tools.

A punch that punched two hundred and thirty-one thousand holes through steel, one-third thicker than its diameter, was hardened and tempered right; this is a vouched-for fact.

Hear what the salesman has to say about his steel, it may mean many dollars to you; every day brings improvements.

The man who tries to make cheap steel do the work of the best is wasting more money than the best would cost.

Cracked steel means misused steel, nine times out of ten. The other may be laid to the steel maker.

Do not have a tool hardened hard, and then make it soft by grinding on a dry wheel.

If a tool with a needle point burns when used at a high speed, blame yourself, not the steel.

Should a solid piece burst some time after being hardened properly, you have cause to blame the steel maker.

The man who does not appreciate a good tool is apt to be a poor mechanic.

Tools made of good steel should pay the entire cost of the good steel in the extra amount of work they do every day over the cheap steel.

Five dollars per pound would be cheap for a steel that would do 10 per cent. more of some kinds of work.

Don't specify percentage of carbon to your steel maker—tell him what sort of a tool you are going to make of it.

Steel makers will give you as high carbon as is safe, always, if they know the use it is to be put to.

Seamy steel usually cracks in a straight line.

A crooked, irregular crack in a tool usually indicates an uneven heat or strain in hardening; don't blame the steel.

Double-edged stone drills should be made "X" shaped before hardening, not have edges left at right angles with each other.

Always turn off a liberal chip when the wearing part is to be under it. Soft spots in hardened tools are often caused by not removing enough from the outer surface.

"Good things come high." There are no exceptions to this rule, not even tool steel.

The word "uniform" is important in the steel question. "Uniform" iron to make "uniform" steel, and "uniform" treatment to produce "uniform" results.

Why spend a good amount in shaping a tool from poor steel, when the same amount spent on a good steel is likely to yield ten times the results.

Beware of the man that has something "just as good" for half the price, unless you were being imposed upon before he arrived.

One-half cent's worth of steel with ten dollars worth of labor on it, is a common thing in some shops.

To do good work, get your tool post as near the work as possible, to make the tool rigid.

Let me see a tool ground by any man, and I will make a good guess of how much he is worth a day.

Give a good man good tools, and they will last him a long time, as he takes pains to care for them.

The man who agrees to make good steel out of poor, is either a knave or a fool, usually the latter.

Good, crucible spring steel, at 4c. per pound, would leave "Damascus" steel far behind in almost any comparative test.

The man "who don't want any better" steel than he is using, is generally using a poor one.

The fellow who is sure that he has the best blacksmith in the State, often has the poorest tool dresser.

EXPLANATION OF TERMS USED.

CHAPTER XV.

Air burnt—A term applied to steel injured by being exposed to an air blast while very hot.

Air hardening steel—A steel susceptible of being hardened by placing in the air at a high heat, and not susceptible of being hardened in water.

Air holes—Small cavities, usually round, frequently found in ingots of steel not properly melted, commonly called "blow holes."

Billet—The form that an ingot assumes after the first operation of hammering.

Burned—That part of forged steel over-heated to the melting point, or very near it.

Charging—The act of putting the iron and medicine into a crucible, open hearth furnace, or Bessemer converter, preparatory to melting or applying more heat.

Check—A small crack usually caused by some defect in the steel or an uneven heat when the steel is quenched.

Chemical terms as applied to steel—These are usually expressed in hundreds of one per cent., or points, for instance, ninety points of carbon would mean .90% of 1%, 125 points would mean 1.25%, etc.

Cold shuts—A section of steel or fin folded over and hammered into the bar by careless hammering.

Dry grained—The term used to describe a fracture of steel which is dull, sandy looking and devoid of the proper glisten and color.

An evidence of poor, weak steel.

Fiery grain—When the grain shows a brilliant lustre, is the effect of too much heating.

Flux—The residue rising on top of a crucible of molten steel from the medicine put in, and the surplus impurities of the iron. Is necessary to prevent the steel from burning.

Glass hard—A term applied to steel hardened as hard as it can be made.

Grades of steel—Term expressing qualities for the high or low grade crucible steel, open hearth or Bessemer steel, etc.

Hot and cold short grain—Hot short means steel that crumbles in hammering when red hot.

Cold short means steel that forges all right, but is brittle and without strength when cold.

Honey combed—Unsound steel, full of blow holes, which become interior seams when drawn into bars.

Steel in this condition is worthless.

Ingot—The first form of cast steel after it has cooled in a mould from being melted.

Killed—A term applied to properly melted steel when it ceases to throw off any more gases or impurities and becomes quiet.

Laps—These are caused by careless hammering or rolling, and consist in a part of the steel being folded over with the scale between so that it cannot unite.

Generally run lengthwise the bar.

Bars having laps should be discarded.

Medicine—The material placed in the crucible with the iron to produce the desired amount of temper and to produce a flux for the iron while being melted.

Over-heated steel—Steel that has been heated too hot in some process of making.

Is shown by a brilliant, fiery fracture.

Over-melted steel—Steel that has been allowed to remain in the melting furnace some time after being properly killed.

Piped steel—Pipes are caused by the exterior walls of the ingot cooling first and becoming rigid so that the natural shrinking process separates the steel in the centre, forming a pipe.

The larger part of this should be on the top of the ingot, as the molten steel usually sinks down and fills the lower cavities, but not always.

Point of carbon—One hundredth part of 1% is also applied to all the other elements of steel.

Pulling—The act of pulling a crucible of molten steel out of the melting furnace.

Shear and double shear steel—Grades of steel made by working blister steel bars.

Skins—Thin layers of decarbonized steel existing under the scale of bars.

Seams—These are made by blow holes becoming elongated, and may exist in the interior of bars as well as on the outside. Interior seams render the steel worthless.

Soaking heat—A thorough through and through heat making the bar thoroughly ductile from surface to centre.

Special tempers—Steel made for specified purposes of the temper best adapted for the intended use.

Stock temper—A medium tempered steel furnished for the dealers and warehouses, stock for general purposes.

Stars—A bright spot or spots showing on the end of a piece of steel, indicating the presence of a pipe or interior seam.

Streaks—Lines shown when steel bursts from small interior seams or elongated air holes, hammered closely together.

Temper—This word, as used by the steel maker, indicates the amount of carbon, etc., in the piece spoken of.

Tempering—This term, as used by the steel consumer, means the act of drawing the temper either by the colors showing or by the thermometer.

Teeming—The act of pouring the molten steel from the crucible into the ingot mould.

Tilting—The act of doing the heavy forging required to reduce the ingot to large sized bars or billets.

Topping—The act of breaking the upper shell of an ingot to secure a sound ingot, and to determine the temper of the ingot.

TABLE OF FRACTIONAL PARTS OF AN INCH

Reduced to their decimals for convenience of close measuring with a Micrometer Caliper.

64ths

$\frac{1}{64} = .015625$

$\frac{3}{64} = .046875$

$\frac{5}{64} = .078125$

$\frac{7}{64} = .109375$

$\frac{9}{64} = .140625$

$\frac{11}{64} = .171875$

$\frac{13}{64} = .203125$

$\frac{15}{64} = .234375$

$\frac{17}{64} = .265625$

$\frac{19}{64} = .296875$

$\frac{21}{64} = .328125$

$\frac{23}{64} = .359375$

$\frac{25}{64} = .390625$

$\frac{27}{64} = .421875$

$\frac{29}{64} = .453125$

$\frac{31}{64} = .484375$

$\frac{33}{64} = .515625$

$\frac{35}{64} = .546875$

$\frac{37}{64} = .578125$

$\frac{39}{64} = .609375$

$\frac{41}{64} = .640625$

$\frac{43}{64} = .671875$

$\frac{45}{64} = .703125$

$\frac{47}{64} = .734375$

$\frac{49}{64} = .765625$

$\frac{51}{64} = .796875$

$\frac{53}{64} = .828125$

$\frac{55}{64} = .859375$

$\frac{57}{64} = .890625$

$\frac{59}{64} = .921875$

$\frac{61}{64} = .953125$

$\frac{63}{64} = .984375$

32ds

$\frac{1}{32} = .03125$

$\frac{3}{32} = .09375$

$\frac{5}{32} = .15625$

$\frac{7}{32} = .21875$

$\frac{9}{32} = .28125$

$\frac{11}{32} = .34375$

$\frac{13}{32} = .40625$

$\frac{15}{32} = .46875$

$\frac{17}{32} = .53125$

$\frac{19}{32} = .59375$

$\frac{21}{32} = .65625$

$\frac{23}{32} = .71875$

$\frac{25}{32} = .78125$

$\frac{27}{32} = .84375$

$\frac{29}{32} = .90625$

$\frac{31}{32} = .96875$

16ths

$\frac{1}{16} = .0625$

$\frac{3}{16} = .1875$

$\frac{5}{16} = .3125$

$\frac{7}{16} = .4375$

$\frac{9}{16} = .5625$

$\frac{11}{16} = .6875$

$\frac{13}{16} = .8125$

$\frac{15}{16} = .9375$

8ths

$\frac{1}{8} = .125$

$\frac{1}{4} = .250$

$\frac{3}{8} = .375$

$\frac{1}{2} = .500$

$\frac{5}{8} = .625$

$\frac{3}{4} = .750$

$\frac{7}{8} = .875$

WEIGHTS OF ROUND, SQUARE AND OCTAGON TOOL STEEL PER LINEAL FOOT.

AMERICAN "FULL SIZES" HAMMERED BARS.

Size. Inch.	Round.	Square	Octagon.	Size. Inch.	Round.	Square.	Octagon.
1/16	.011	.014	.0116	3	25.4	32.4	26.8
1/8	.044	.056	.046	3 1/8	27.6	35.1	29.1
3/16	.099	.126	.104	3 1/4	29.8	38.0	31.4
1/4	.177	.225	.186	3 3/8	32.2	41.0	33.9
5/16	.276	.351	.290	3 1/2	34.6	44.1	36.5
3/8	.397	.506	.419	3 5/8	37.1	47.3	39.1
7/16	.541	.689	.570	3 3/4	39.7	50.6	41.9
1/2	.707	.90	.745	3 7/8	42.4	54.0	44.7
9/16	.895	1.13	.943	4	45.2	57.6	47.6
5/8	1.10	1.40	1.16	4 1/8	48.1	61.2	50.7
11/16	1.33	1.70	1.40	4 1/4	51.0	65.0	53.8
3/4	1.59	2.02	1.67	4 3/8	54.1	68.9	57.0
13/16	1.86	2.37	1.96	4 1/2	57.2	72.9	60.3
7/8	2.16	2.75	2.28	4 5/8	60.4	77.0	63.7
15/16	2.48	3.16	2.62	4 3/4	63.7	81.2	67.2
1	2.82	3.60	2.98	4 7/8	67.1	85.5	70.8
1 1/8	3.57	4.55	3.77	5	70.6	90.0	74.5
1 1/4	4.41	5.62	4.65	5 1/8	74.2	94.5	78.2
1 3/8	5.34	6.80	5.63	5 1/4	77.9	99.2	82.1
1 1/2	6.36	8.10	6.70	5 3/8	81.6	104.0	86.1
1 5/8	7.46	9.50	7.87	5 1/2	85.5	108.0	90.1
1 3/4	8.65	11.02	9.12	5 5/8	89.4	113.0	94.3
1 7/8	9.94	12.6	10.04	5 3/4	93.4	119.0	98.5
2	11.3	14.4	11.9	5 7/8	97.4	124.0	102.0
2 1/8	12.7	16.2	13.4	6	101.0	129.0	107.0
2 1/4	14.3	18.2	15.0	7	138.0	176.0	146.0
2 3/8	15.9	20.3	16.8	8	180.0	230.0	190.0
2 1/2	17.6	22.5	18.6	9	229.0	291.0	241.0
2 5/8	19.4	24.8	20.5	10	282.0	360.0	298.0
2 3/4	21.3	27.2	22.5	11	342.0	435.0	360.0
2 7/8	23.3	29.7	24.6	12	407.0	518.0	429.0

WEIGHTS OF FLAT SIZES PER LINEAL FOOT.

TOOL STEEL "AMERICAN FULL SIZES." HAMMERED BARS.

Sizes.	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2
1/16	.028	.042	.056	.070	.084	.098	.112	.127	.141	.155	.169	.183	.187	.211	.225	.253	.281	.309	.338
1/8		.084	.112	.140	.168	.196	.224	.254	.282	.310	.338	.366	.394	.422	.45	.506	.562	.618	.675
3/16			.168	.210	.252	.294	.336	.381	.423	.465	.506	.548	.591	.633	.675	.759	.844	.927	1.01
1/4				.280	.336	.392	.449	.508	.564	.620	.675	.731	.788	.844	.90	1.01	1.12	1.23	1.35
5/16					.420	.490	.562	.635	.705	.715	.844	.914	.984	1.05	1.12	1.26	1.40	1.54	1.68
3/8						.588	.674	.762	.846	.930	1.01	1.10	1.18	1.26	1.35	1.51	1.68	1 85	2 02
7/16							.786	.889	.987	1.08	1.18	1.28	1.37	1.47	1.57	1.77	1.96	2.16	2.36
1/2								1.01	1.12	1.24	1.35	1.46	1.57	1.68	1.80	2.02	2.25	2.47	2.70
9/16									1.26	1.39	1.51	1.64	1.77	1.89	2.02	2.27	2.53	2 78	3 03
5/8										1.55	1.68	1.82	1.96	2.11	2.25	2.53	2.81	3 09	3 37
11/16											1.85	2.01	2.16	2.32	2.47	2.78	3.09	3 40	3 71
3/4												2.19	2.36	2.53	2.70	3.03	3 37	3 71	4 05
13/16													2.55	2.74	2.92	3.28	3 65	4 01	4.41
7/8														2.95	3.15	3.54	3 93	4 33	4 72
15/16															3.37	3.80	4 22	4 64	5.06
1																4.05	4 50	4 95	5.40
1 1/8																	5.06	5 56	6 07
1 1/4																		6.18	6.75
1 3/8																			7.42

WEIGHTS OF FLAT SIZES PER LINEAL FOOT.
TOOL STEEL "AMERICAN FULL SIZES." HAMMERED BARS.

Sizes.	1⅝	1¾	1⅞	2	2⅛	2¼	2⅜	2½	2⅝	2¾	2⅞	3	3⅛	3¼	3⅜	3½	3⅝	3¾	3⅞
½	2.92	3.15	3.37	3.60	3.82	4.05	4.27	4.50	4.72	4.95	5.17	5.40	5.62	5.85	6.07	6.30	6.52	6.75	6.98
9/16	3.29	3.54	3.79	4.05	4.30	4.55	4.80	5.06	5.31	5.56	5.82	6.07	6.32	6.58	6.83	7.09	7.34	7.59	7.85
⅝	3.65	3.93	4.21	4.50	4.78	5.06	5.34	5.62	5.90	6.18	6.46	6.75	7.03	7.31	7.59	7.87	8.15	8.43	8.72
11/16	4.02	4.32	4.64	4.95	5.25	5.56	5.87	6.18	6.49	6.80	7.11	7.42	7.73	8.04	8.35	8.66	8.96	9.27	9.59
¾	4.38	4.72	5.06	5.40	5.73	6.07	6.41	6.75	7.08	7.42	7.76	8.10	8.43	8.77	9.11	9.45	9.78	10.1	10.45
13/16	4.75	5.11	5.48	5.85	6.21	6.58	6.95	7.31	7.67	8.04	8.41	8.78	9.14	9.49	9.86	10.23	10.59	10.95	11.33
⅞	5.11	5.51	5.90	6.30	6.69	7.08	7.48	7.87	8.26	8.66	9.05	9.45	9.84	10.2	10.6	11.0	11.4	11.8	12.2
1	5.85	6.30	6.75	7.20	7.65	8.10	8.55	9.00	9.45	9.90	10.03	10.8	11.2	11.7	12.1	12.6	13.0	13.5	13.95
1⅛	6.58	7.08	7.59	8.10	8.60	9.11	9.61	10.1	10.6	11.1	11.6	12.1	12.6	13.1	13.6	14.1	14.6	15.1	15.65
1¼	7.31	7.87	8.43	9.00	9.56	10.1	10.6	11.2	11.8	12.3	12.9	13.5	14.0	14.6	15.1	15.7	16.3	16.8	17.4
1⅜	8.04	8.66	9.28	9.90	10.5	11.1	11.7	12.3	12.9	13.6	14.2	14.8	15.4	16.0	16.7	17.3	17.9	18.5	19.15
1½	8.77	9.45	10.1	10.8	11.4	12.1	12.8	13.5	14.1	14.8	15.5	16.2	16.8	17.5	18.2	18.9	19.5	20.2	20 9
1⅝	9.50	10.23	10.9	11.7	12.4	13.1	13.8	14.6	15.3	16.0	16.8	17.5	18.2	19.0	19.7	20.4	21.2	21.9	22.65
1¾	10.23	11.02	11.8	12.6	13.3	14.1	14.9	15.7	16.5	17.3	18.1	18.9	19.6	20.4	21.2	22.0	22.8	23.6	24.4
1⅞	10.9	11.8	12.6	13.5	14.3	15.1	16.0	16.8	17.7	18.5	19.4	20.2	21.0	21.9	22.7	23.6	24.4	25.3	26.15
2	11.7	12.6	13.5	14.4	15.3	16.2	17.1	18.0	18.9	19.8	20.7	21.6	22.5	23.4	24.3	25.2	26.1	27.0	27.9
2⅛	12.4	13.3	14.3	15.3	16.2	17.2	18.1	19.1	20.0	21.0	21.9	22.9	23.9	24.8	25.8	26.7	27.7	28.6	29.6
2¼	13.1	14.1	15.4	16.2	17.2	18.2	19.2	20.2	21.2	22.2	23.2	24.3	25.3	26.3	27.3	28.3	29.3	30.3	31.8
2⅜	13.8	14.9	16.0	17.1	18.1	19.2	20.3	21.3	22.4	23.5	24.5	25.6	26.7	27.7	28.8	29.9	30.9	32.0	33.1

WEIGHTS OF ONE SQUARE FOOT OF SHEET STEEL, TOOL QUALITY.

STUBBS' GAUGE (ENGLISH STANDARD).

Gauge No. Bir'm Gauge	Thickness, Decimal.	Pounds per Sq. Foot.	No. of Bir'm Gauge.	Thickness, Decimal.	Pounds per Sq. Foot.
0000	.454	19.5	17	.058	2.49
000	.425	18.2	18	.049	2.10
00	.380	16.3	19	.042	1.80
0	.340	14.6	20	.035	1.50
1	.300	12.9	21	.032	1.37
2	.284	12.2	22	.028	1.20
3	.259	11.1	23	.025	1.07
4	.238	10.2	24	.022	.946
5	.220	9.46	25	.020	.860
6	.203	8.72	26	.018	.774
7	.180	7.74	27	.016	.688
8	.165	7.09	28	.014	.602
9	.148	6.36	29	.013	.559
10	.134	5.76	30	.012	.516
11	.120	5.16	31	.010	.430
12	.109	4.68	32	.009	.387
13	.095	4.08	33	.008	.344
14	.083	3.56	34	.007	.301
15	.072	3.09	35	.005	.215
16	.065	2.79	36	.004	.172

WEIGHTS OF ROUND AND SQUARE SOFT MACHINERY ROLLED STEEL

Per lineal foot. One cubic foot of steel weighs 490 lbs.

Sizes in Inches	● Weight in Lbs.	■ Weight in Lbs.	Sizes in Inches	● Weight in Lbs.	■ Weight in Lbs.	Sizes in Inches	● Weight in Lbs.	■ Weight in Lbs.
1/16	.010	.013	4 1/16	44.07	56.11	8 1/16	173.6	221.0
1/8	.042	.053	4 1/8	45.44	57.85	8 1/8	176.3	224.5
3/16	.094	.119	4 3/16	46.83	59.62	8 3/16	179.0	228.0
1/4	.167	.212	4 1/4	48.24	61.41	8 1/4	181.8	231.4
5/16	.261	.333	4 5/16	49.66	63.23	8 5/16	184.5	234.9
3/8	.375	.478	4 3/8	51.11	65.08	8 3/8	187.3	238.5
7/16	.511	.651	4 7/16	52.58	66.95	8 7/16	190.1	242.0
1/2	.667	.850	4 1/2	54.07	68.85	8 1/2	193.0	245.6
9/16	.845	1.076	4 9/16	55.59	70.78	8 9/16	195.7	249 3
5/8	1.043	1.328	4 5/8	57.12	72.73	8 5/8	198.7	252.9
11/16	1.262	1.608	4 11/16	58.67	74.70	8 11/16	201.6	256.6
3/4	1.502	1.913	4 3/4	60.25	76.71	8 3/4	204.4	260.3
13/16	1.763	2.245	4 13/16	61.84	78.74	8 13/16	207.4	264.1
7/8	2.044	2.603	4 7/8	63.46	80.81	8 7/8	210.3	267.9
15/16	2.347	2.989	4 15/16	65.10	82.89	8 15/16	213.3	271.6
1	2.670	3.400	5	66.76	85.00	9	216.3	275.4
1 1/16	3.014	3.838	5 1/16	68.44	87.14	9 1/16	219.3	279.3
1 1/8	3.379	4.303	5 1/8	70.14	89.30	9 1/8	222.4	283.2
1 3/16	3.766	4.795	5 3/16	71.86	91.49	9 3/16	225.4	287.0
1 1/4	4.173	5.312	5 1/4	73.60	93.72	9 1/4	228.5	290.9
1 5/16	4.600	5.857	5 5/16	75.37	95.96	9 5/16	231.5	294.9
1 3/8	5.049	6.428	5 3/8	77.15	98.23	9 3/8	234.7	298.9
1 7/16	5.518	7.026	5 7/16	78.95	100.5	9 7/16	237.9	302.8
1 1/2	6.008	7.650	5 1/2	80.77	102.8	9 1/2	241.0	306.8
1 9/16	6.520	8.301	5 9/16	82.62	105.2	9 9/16	244.2	310.9
1 5/8	7.051	8.978	5 5/8	84.49	107.6	9 5/8	247.4	315.0
1 11/16	7.604	9.682	5 11/16	86.38	110.0	9 11/16	250.6	319.1
1 3/4	8.178	10.41	5 3/4	88.29	112.4	9 3/4	253.9	323.2
1 13/16	8.773	11.17	5 13/16	90.22	114.9	9 13/16	257.1	327.4
1 7/8	9.388	11.95	5 7/8	92.17	117.4	9 7/8	260.4	331.6
1 15/16	10.02	12.76	5 15/16	94.14	119.9	9 15/16	263.7	335.8
2	10.68	13.60	6	96 14	122.4	10	267.0	340.0
2 1/16	11.36	14 46	6 1/16	98.14	125.0	10 1/16	270.4	344.3
2 1/8	12.06	15.35	6 1/8	100.2	127.6	10 1/8	273.8	348.5
2 3/16	12.78	16.27	6 3/16	102.2	130.2	10 3/16	277.1	352.9
2 1/4	13.52	17.22	6 1/4	104.3	132.8	10 1/4	280.6	357.2
2 5/16	14.28	18.19	6 5/16	106.4	135.5	10 5/16	284.0	361.6
2 3/8	15.07	19.18	6 3/8	108.5	138.2	10 3/8	287.4	366.0
2 7/16	15.86	20.20	6 7/16	110.7	140.9	10 7/16	290.9	370.4
2 1/2	16.69	21 25	6 1/2	112.8	143.6	10 1/2	294.4	374.9
2 9/16	17.53	22.33	6 9/16	114.9	146.5	10 9/16	297.9	379.4
2 5/8	18.40	23.43	6 5/8	117.2	149.2	10 5/8	301.4	383.8
2 11/16	19.29	24.56	6 11/16	119.4	152.1	10 11/16	305.0	388.3
2 3/4	20.20	25.00	6 3/4	121.7	154.9	10 3/4	308.6	392.9
2 13/16	21.12	26.90	6 13/16	123.9	157.8	10 13/16	312.2	397.5
2 7/8	22.07	28.10	6 7/8	126.2	160.8	10 7/8	315.8	402.1
2 15/16	23.04	29.34	6 15/16	128.5	163.6	10 15/16	319.5	406.8
3	24.03	30.60	7	130.9	166.6	11	323.1	411.4
3 1/16	25.04	31.89	7 1/16	133.2	169.6	11 1/16	326.8	416.1
3 1/8	26.08	33.20	7 1/8	135.6	172.6	11 1/8	330.5	420.9
3 3/16	27.13	34.55	7 3/16	137.9	175.6	11 3/16	334.3	425.5
3 1/4	28.20	35.92	7 1/4	140.4	178.7	11 1/4	337.9	430.3
3 5/16	29.30	37.31	7 5/16	142.8	181.8	11 5/16	341.7	435.1
3 3/8	30.42	38.73	7 3/8	145 3	184.9	11 3/8	345.5	439.9
3 7/16	31.56	40.18	7 7/16	147.7	188.1	11 7/16	349.4	444.8
3 1/2	32.71	41.65	7 1/2	150.2	191.3	11 1/2	353.1	449.6
3 9/16	33.90	43.14	7 9/16	152.7	194.4	11 9/16	357.0	454.5
3 5/8	35.09	44.68	7 5/8	155.2	197.7	11 5/8	360.9	459.5
3 11/16	36.31	46.24	7 11/16	157.8	200.9	11 11/16	364.8	464.4
3 3/4	37.56	47.82	7 3/4	160.3	204.2	11 3/4	368.6	469.4
3 13/16	38.81	49.42	7 13/16	163.0	207.6	11 13/16	372.6	474.4
3 7/8	40.10	51.05	7 7/8	165.6	210 8	11 7/8	376.6	479.5
3 15/16	41.40	52.71	7 15/16	168.2	214.2	11 15/16	380.6	484.5
4	42.73	54.40	8	171.0	217.6	......	....	....

WEIGHTS OF FLAT ROLLED SOFT MACHINERY STEEL BARS.

Per lineal foot in pounds. One cubic foot of steel weighs 489.6 lbs.

Thickness in Inches.	Width of Bars.																						
	1″	1¼″	1½″	1¾″	2″	2¼″	2½″	2¾″	3″	3¼″	3½″	3¾″	4″	4¼″	4½″	4¾″	5″	5¼″	5½″	5¾″	6″	6¼″	6½″	6¾″
1/16	.212	.265	.319	.372	.425	.478	.531	.584	.637	.690	.743	.797	.849	.902	.956	1.01	1.06	1.11	1.17	1.22	1.28	1.33	1.38	1.43
1/8	.425	.531	.637	.743	.849	.956	1.06	1.17	1.28	1.38	1.49	1.59	1.70	1.81	1.92	2.02	2.12	2.23	2.34	2.45	2.55	2.65	2.76	2.83
3/16	.638	.797	.957	1.11	1.28	1.44	1.59	1.75	1.91	2.07	2.23	2.39	2.55	2.71	2.87	3.03	3.19	3.35	3.51	3.67	3.83	3.99	4.14	4.30
1/4	.850	1.06	1.28	1.49	1.70	1.91	2.12	2.34	2.55	2.76	2.98	3.19	3.40	3.61	3.83	4.04	4.25	4.46	4.67	4.89	5.10	5.31	5.53	5.74
5/16	1.06	1.33	1.59	1.86	2.12	2.39	2.65	2.92	3.19	3.45	3.72	3.99	4.25	4.52	4.78	5.05	5.31	5.58	5.84	6.11	6.38	6.64	6.90	7.17
3/8	1.28	1.59	1.92	2.23	2.55	2.87	3.19	3.51	3.83	4.15	4.47	4.78	5.10	5.42	5.74	6.06	6.38	6.69	7.02	7.34	7.65	7.97	8.29	8.61
7/16	1.49	1.86	2.23	2.60	2.98	3.35	3.72	4.09	4.46	4.83	5.20	5.58	5.95	6.32	6.70	7.07	7.44	7.81	8.18	8.56	8.93	9.29	9.67	10.04
1/2	1.70	2.12	2.55	2.98	3.40	3.83	4.25	4.67	5.10	5.53	5.95	6.38	6.80	7.22	7.65	8.08	8.50	8.93	9.35	9.77	10.20	10.63	11.05	11.48
9/16	1.92	2.39	2.87	3.35	3.83	4.30	4.78	5.26	5.74	6.22	6.70	7.17	7.65	8.13	8.61	9.09	9.57	10.04	10.52	11.00	11.48	11.95	12.43	12.91
5/8	2.12	2.65	3.19	3.72	4.25	4.78	5.31	5.84	6.38	6.91	7.44	7.97	8.50	9.03	9.57	10.10	10.63	11.16	11.69	12.22	12.75	13.28	13.81	14.34
11/16	2.34	2.92	3.51	4.09	4.67	5.26	5.84	6.43	7.02	7.60	8.18	8.76	9.35	9.93	10.52	11.11	11.69	12.27	12.85	13.44	14.03	14.61	15.20	15.78
3/4	2.55	3.19	3.83	4.47	5.10	5.75	6.38	7.02	7.65	8.29	8.93	9.57	10.20	10.84	11.48	12.12	12.75	13.39	14.03	14.67	15.30	15.94	16.58	17.22
13/16	2.76	3.45	4.14	4.84	5.53	6.21	6.90	7.60	8.29	8.98	9.67	10.36	11.05	11.74	12.43	13.12	13.81	14.50	15.19	15.88	16.58	17.27	17.95	18.65
7/8	2.98	3.72	4.47	5.20	5.95	6.69	7.44	8.18	8.93	9.67	10.41	11.16	11.90	12.65	13.39	14.13	14.87	15.62	16.36	17.10	17.85	18.60	19.34	20.08
15/16	3.19	3.99	4.78	5.58	6.38	7.18	7.97	8.77	9.57	10.36	11.16	11.95	12.75	13.55	14.34	15.14	15.94	16.74	17.53	18.33	19.13	19.92	20.72	21.51
1	3.40	4.25	5.10	5.95	6.80	7.65	8.50	9.35	10.20	11.05	11.90	12.75	13.60	14.45	15.30	16.15	17.00	17.85	18.70	19.55	20.40	21.25	22.10	22.95
1 1/16	3.61	4.52	5.42	6.32	7.22	8.13	9.03	9.93	10.84	11.74	12.65	13.55	14.45	15.35	16.26	17.16	18.06	18.96	19.87	20.77	21.68	22.58	23.48	24.39
1 1/8	3.83	4.78	5.74	6.70	7.65	8.61	9.57	10.52	11.48	12.43	13.39	14.34	15.30	16.26	17.22	18.17	19.13	20.08	21.04	21.99	22.95	23.91	24.87	25.82
1 3/16	4.04	5.05	6.06	7.07	8.08	9.09	10.10	11.11	12.12	13.12	14.13	15.14	16.15	17.16	18.17	19.18	20.19	21.20	22.21	23.22	24.23	25.23	26.24	27.25
1 1/4	4.25	5.31	6.38	7.44	8.50	9.57	10.63	11.69	12.75	13.81	14.87	15.94	17.00	18.06	19.13	20.19	21.25	22.32	23.38	24.44	25.50	26.56	27.62	28.69
1 5/16	4.46	5.58	6.69	7.81	8.93	10.04	11.16	12.27	13.39	14.50	15.62	16.74	17.85	18.96	20.08	21.20	22.32	23.43	24.54	25.66	26.78	27.90	29.01	30.12
1 3/8	4.67	5.84	7.02	8.18	9.35	10.52	11.69	12.85	14.03	15.20	16.36	17.53	18.70	19.87	21.04	22.21	23.38	24.54	25.71	26.88	28.05	29.22	30.39	31.56
1 7/16	4.89	6.11	7.34	8.56	9.78	11.00	12.22	13.44	14.66	15.88	17.10	18.33	19.55	20.77	21.99	23.22	24.44	25.66	26.88	28.10	29.33	30.55	31.77	32.99
1 1/2	5.10	6.38	7.65	8.93	10.20	11.48	12.75	14.03	15.30	16.58	17.85	19.13	20.40	21.68	22.95	24.23	25.50	26.78	28.05	29.33	30.60	31.88	33.15	34.43
1 9/16	5.32	6.64	7.97	9.30	10.63	11.95	13.28	14.61	15.94	17.27	18.60	19.92	21.25	22.58	23.91	25.24	26.57	27.89	29.22	30.55	31.88	33.20	34.53	35.86
1 5/8	5.52	6.90	8.29	9.67	11.05	12.43	13.81	15.19	16.58	17.96	19.34	20.72	22.10	23.48	24.87	26.25	27.63	29.01	30.39	31.77	33.15	34.53	35.91	37.29
1 11/16	5.74	7.17	8.61	10.04	11.47	12.91	14.34	15.78	17.22	18.65	20.08	21.51	22.95	24.38	25.82	27.26	28.69	30.12	31.55	32.99	34.43	35.86	37.30	38.73
1 3/4	5.95	7.44	8.93	10.42	11.90	13.40	14.88	16.37	17.85	19.34	20.83	22.32	23.80	25.29	26.78	28.27	29.75	31.24	32.73	34.22	35.70	37.19	38.68	40.17
1 13/16	6.16	7.70	9.24	10.79	12.33	13.86	15.40	16.95	18.49	20.03	21.57	23.11	24.65	26.19	27.73	29.27	30.81	32.35	33.89	35.43	36.98	38.52	40.05	41.60
1 7/8	6.38	7.97	9.57	11.15	12.75	14.34	15.94	17.53	19.13	20.72	22.31	23.91	25.50	27.10	28.69	30.28	31.87	33.47	35.06	36.65	38.25	39.85	41.44	43.03
1 15/16	6.59	8.24	9.88	11.53	13.18	14.83	16.47	18.12	19.77	21.41	23.06	24.70	26.35	28.00	29.64	31.29	32.94	34.59	36.23	37.88	39.53	41.17	42.82	44.46
2	6.80	8.50	10.20	11.90	13.60	15.30	17.00	18.70	20.40	22.10	23.80	25.50	27.20	28.90	30.60	32.30	34.00	35.70	37.40	39.10	40.80	42.50	44.20	45.90

WEIGHTS OF FLAT ROLLED SOFT MACHINERY STEEL BARS—Continued.

Per lineal foot in pounds. One cubic foot of steel weighs 489.6 lbs.

Thickness in Inches.	Width of Bars.											
	7"	7 1/4"	7 1/2"	7 3/4"	8"	8 1/4"	8 1/2"	8 3/4"	9"	9 1/4"	9 1/2"	9 3/4"
1/16	1.49	1 54	1.59	1.65	1.70	1.75	1.81	1.86	1 92	1.97	2.02	2.07
1/8	2.98	3.08	3.18	3.29	3.40	3.50	3.62	3.72	3.83	3.92	4.04	4.14
3/16	4.46	4.62	4.78	4.94	5.10	5.26	5.42	5.58	5.74	5.90	6.06	6.22
1/4	5.95	6.16	6.36	6.58	6.80	7.01	7.22	7.43	7.65	7.86	8.08	8.29
5/16	7.44	7.70	7.97	8 23	8.50	8.76	9.03	9.29	9.56	9.83	10.10	10.36
3/8	8.93	9.25	9 57	9.88	10.20	10.52	10.84	11.16	11.48	11.80	12.12	12.44
7/16	10.41	10.78	11.16	11.53	11.90	12.27	12.64	13.02	13.40	13.76	14 14	14.51
1/2	11.90	12.32	12.75	13.18	13.60	14.03	14.44	14.87	15.30	15.73	16.16	16.58
9/16	13.39	13.86	14.34	14.82	15.30	15.78	16.26	16.74	17.22	17.69	18.18	18.65
5/8	14.87	15.40	15.94	16 47	17.00	17.53	18.06	18.59	19.13	19.65	20.19	20.72
11/16	16.36	16.94	17.53	18.12	18.70	19.28	19.86	20.45	21.04	21.62	22 21	22.79
3/4	17.85	18.49	19.13	19.77	20.40	21.04	21.68	22.32	22.96	23.59	24.23	24.86
13/16	19.34	20.03	20.72	21.41	22.10	22.79	23.48	24.17	24.86	25.55	26.24	26.94
7/8	20.83	21.57	22.32	23.05	23.80	24.55	25.30	26.04	26.78	27.52	28.26	29.01
15/16	22.32	23.11	23.91	24.70	25.50	26.30	27.10	27.89	28.69	29.49	30.28	31.08
1	23.80	24.65	25.50	26.35	27.20	28.05	28.90	29.75	30.60	31.45	32.30	33.15
1 1/16	25.29	26.19	27.10	28.00	28.90	29.80	30.70	31.61	32.52	33.41	34.32	35.22
1 1/8	26.78	27.73	28.68	29.64	30.60	31.56	32.52	33.47	34.43	35.38	36.34	37.29
1 3/16	28.26	29 27	30.28	31.29	32.30	33.31	34.32	35.33	36.34	37.35	38.36	39.37
1 1/4	29.75	30.81	31.88	32.94	34.00	35.06	36.12	37.20	38.26	39.31	40.37	41.44
1 5/16	31.23	32.35	33.48	34.59	35.70	36.81	37.93	39.05	40.16	41.28	42.40	43.52
1 3/8	32.72	33.89	35.06	36.23	37.40	38.57	39.74	40.91	42.08	43.25	44.41	45.58
1 7/16	34.21	35.44	36.66	37.88	39.10	40.32	41.54	42.77	44.00	45.22	46.44	47.66
1 1/2	35.70	36.98	38.26	39.53	40.80	42.08	43.35	44.63	45.90	47.18	48.45	49.73
1 9/16	37.19	38.51	39.84	41.17	42.50	43.83	45.16	46.49	47.82	49.14	50.48	51.80
1 5/8	38.67	40 05	41.44	42.82	44.20	45.58	46.96	48.34	49.73	51.10	52.49	53.87
1 11/16	40.16	41.59	43 03	44.47	45.90	47.33	48.76	50.20	51.64	53.07	54.51	55.94
1 3/4	41.65	43.14	44 63	46.12	47.60	49.09	50.58	52.07	53.56	55.04	56.53	58.01
1 13/16	43.14	44.68	46.22	47.76	49.30	50.84	52.38	53.92	55.46	57.00	58.54	60 09
1 7/8	44.63	46.22	47.82	49.40	51.00	52.60	54.20	55.79	57.38	58.97	60.56	62.16
1 15/16	46.12	47.76	49.41	51.05	52.70	54.35	56.00	57.64	59.29	60.94	62.58	64.23
2	47.60	49.30	51.00	52.70	54.40	56.10	57.80	59.50	61.20	62.90	64.60	66.30

Thickness in Inches.	Width of Bars.											
	10"	10 1/4"	10 1/2"	10 3/4"	11"	11 1/4"	11 1/2"	11 3/4"	12"	12 1/4"	12 1/2"	12 3/4"
1/16	2.12	2.18	2.23	2.28	2.34	2.39	2.45	2.50	2.55	2.60	2.65	2.70
1/8	4.25	4.36	4.46	4.56	4.67	4.79	4.90	5.00	5.10	5.20	5 31	5.41
3/16	6.38	6.54	6.70	6.86	7.02	7.17	7.32	7.49	7.65	7.82	7.98	8.13
1/4	8.50	8.71	8.92	9.14	9.34	9.57	9.78	10.00	10.20	10.42	10.63	10.84
5/16	10.62	10.89	11.16	11.42	11.68	11.95	12.22	12.49	12.75	13.01	13.28	13.55
3/8	12.75	13.07	13.39	13.71	14.03	14.35	14.68	14.99	15.30	15.62	15.94	16.26
7/16	14.88	15.25	15.62	15.99	16.36	16.74	17.12	17.49	17.85	18.23	18.60	18.97
1/2	17.00	17.42	17.85	18.28	18.70	19.13	19.55	19.97	20.40	20.82	21.25	21.67
9/16	19.14	19.61	20.08	20.56	21.02	21.51	22.00	22.48	22.95	23 43	23.90	24.39
5/8	21.25	21.78	22.32	22.85	23.38	23.91	24.44	24.97	25.50	26.03	26.56	27.09
11/16	23.38	23.96	24.54	25.13	25.70	26.30	26.88	27.47	28.05	28.64	29.22	29 80
3/4	25.50	26.14	26.78	27.42	28.05	28.68	29.33	29.97	30.60	31.25	31.88	32.52
13/16	27.62	28.32	29.00	29.69	30.40	31.08	31.76	32.46	33.15	33.83	34.53	35.22
7/8	29.75	30.50	31.24	31.98	32.72	33.47	34.21	34.95	35.70	36.44	37 19	37.93
15/16	31.88	32.67	33.48	34.28	35.06	35.86	36.66	37.46	38.25	39.05	39.84	40.64
1	34 00	34.85	35.70	36.55	37.40	38.25	39.10	39.95	40.80	41.65	42.50	43.35
1 1/16	36.12	37.03	37.92	38.83	39.74	40.64	41.54	42.45	43.35	44.25	45.16	46.06
1 1/8	38.25	39.21	40.17	41.12	42.08	43.04	44.00	44.94	45.90	46.86	47.82	48.77
1 3/16	40.38	41.39	42.40	43.40	44.42	45.42	46.44	47.45	48.45	49.46	50.46	51.48
1 1/4	42.50	43.56	44.63	45.69	46 76	47.82	48.88	49.94	51.00	52.06	53.12	54.19
1 5/16	44.64	45.75	46.86	47.97	49.08	50.20	51.32	52.44	53.55	54.67	55.78	56.90
1 3/8	46.75	47.92	49.08	50.25	51.42	52 59	53.76	54.93	56.10	57.27	58.44	59 60
1 7/16	48.88	50.10	51.32	52.54	53.76	54.99	56.21	57.43	58.65	59.87	61.10	62.32
1 1/2	51.00	52.28	53.55	54.83	56.10	57 37	58.65	59.93	61.20	62.48	63.75	65.03
1 9/16	53.14	54.46	55.78	57.11	58.42	59.76	61.10	62.43	63.75	65.08	66.40	67.74
1 5/8	55.25	56.63	58.02	59.40	60.78	62.16	63.54	64.92	66.30	67.68	69.06	70.44
1 11/16	57.38	58.81	60.24	61.68	63.10	64.55	65 98	67.42	68.85	70.29	71.72	73.15
1 3/4	59.50	60.99	62.48	63 97	65.45	66.93	68.43	69.92	71.40	72.90	74.38	75.87
1 13/16	61.62	63.17	64.70	66.24	67.80	69.33	70.86	72.41	73.95	75.48	77.03	78.57
1 7/8	63.75	65.35	66.94	68.53	70.12	71.72	73.31	74.90	76.50	78.09	79.69	81.28
1 15/16	65.88	67.52	69.18	70.83	72.46	74.11	75.76	77.41	79.05	80.70	82.34	83.99
2	68.00	69.70	71.40	73.10	74.80	76.50	78.20	79.90	81.60	83.30	85.00	86.70

WEIGHTS OF SOFT STEEL SHEETS AND PLATES.

By Standard Gauges.

No. of Gauge or Thickness of Sheet.	Approximate Thickness in Inches.				Weight per Square Foot in Pounds.					
	U. S. Standard adopted by U. S. Government July 1, 1893.		Birmingham Wire Gauge	American or Brown & Sharpe's	U. S. Standard	Mill Standard	Birmingham Wire Gauge		American or Brown & Sharpe's	
	Fractions.	Decimals.	Decimals.	Decimals.	Steel	Steel	Steel	Iron	Steel	Iron
7-0's	1-2	.5	-----	-----	20.00	20.4	-----	-----	-----	-----
6-0's	15-32	.468	-----	-----	18.75	19.125	-----	-----	-----	-----
5-0's	7-16	.437	-----	-----	17.50	17.85	-----	-----	-----	-----
0000	13-32	.406	.454	.46	16.25	16.575	18.46	18.22	18.77	18.40
000	3-8	.375	.425	.409	15.	15.30	17.28	17.05	16.71	16.38
00	11-32	.343	.38	.364	13.75	14.025	15.45	15.25	14.88	14.59
0	5-16	.312	.34	.324	12.50	12.75	13.82	13.64	13.26	13.00
1	9-32	.281	.30	.289	11.25	11.275	12.20	12.04	11.80	11.57
2	17-64	.265	.284	.257	10.625	10.8375	11.55	11.40	10.51	10.30
3	1-4	.25	.259	.229	10.	10.2	10.53	10.39	9.36	9.18
4	15-64	.234	.238	.204	9.375	9.5625	9.68	9 55	8.34	8.17
5	7-32	.218	.22	.181	8.75	8.925	8.95	8.83	7.42	7.28
6	13-64	.203	.203	.162	8.125	8.2875	8.25	8.15	6.61	6.48
7	3-16	.187	.18	.144	7.5	7.65	7.32	7.22	5.89	5.77
8	11-64	.171	.165	.128	6.875	7.0125	6.71	6.62	5.24	5.14
9	5-32	.156	.148	.114	6.25	6.375	6.02	5.94	4.67	4.58
10	9-64	.140	.134	.101	5.625	5.7375	5.45	5.38	4.16	4.08
11	1-8	.125	.12	.09	5.	5.1	4.88	4.82	3.70	3.63
12	7-64	.109	.109	.08	4.375	4.625	4.43	4.37	3.30	3.23
13	3-32	.093	.095	.072	3.75	3.825	3.86	3.81	2.94	2.88
14	5-64	.078	.083	.064	3.125	3.1875	3.37	3.33	2.62	2.56
15	9-128	.070	.072	.057	2.8125	2 86875	2.93	2.89	2.33	2.28
16	1-16	.062	.065	.05	2.5	2.55	2.64	2.61	2.07	2.03
17	9-160	.056	.058	.045	2.25	2.295	2.36	2.33	1.85	1.81
18	1-20	.05	.049	.04	2.	2.04	1.99	1.97	1.64	1.61
19	7-160	.043	.042	.035	1.75	1.785	1.71	1.69	1.46	1.44
20	3-80	.037	.035	.032	1.50	1.53	1.42	1.40	1.31	1.28
21	11-320	.034	.032	.028	1.375	1.4025	1.30	1.28	1.16	1.14
22	1-32	.031	.028	.025	1.25	1.275	1.14	1.12	1.03	1.01
23	9-320	.028	.025	.022	1.125	1.1475	1.02	1.00	.922	.904
24	1-40	.025	.022	.020	1.	1.02	.895	.883	.82	.804
25	7-320	.021	.02	.017	.875	.8925	.813	.803	.73	.716
26	3-160	.018	.018	.015	.75	.765	.732	.722	.649	.636
27	11-640	.017	.016	.014	.6875	.70125	.651	.642	.579	.568
28	1-64	.015	.014	.012	.625	.6375	.569	.562	.514	.504
29	9-640	.014	.013	.011	.5625	.57375	-----	-----	.461	.452
30	1-80	.012	.012	.01	.5	.51	-----	-----	.408	.46
31	7-640	.010	.001	.008	.4375	.44625	-----	-----	.363	.356
32	13-1280	.010	.009	.008	.4062	.414375	-----	-----	.326	.320
33	3-320	.009	.008	.007	.375	.3825	-----	-----	.29	.284
34	11-1280	.008	.007	.006	.3437	.350625	-----	-----	.257	.252
35	5-640	.007	.005	.005	.3125	.31885	-----	-----	.228	.224
36	9-1280	.007	.004	-----	.2812	.286875	-----	-----	-----	-----
37	17-2560	.006	-----	-----	.2656	.2709375	-----	-----	-----	-----
38	1-160	.006	-----	-----	.25	.255	-----	-----	-----	-----

The U. S. Standard Gauge is the one commonly used in the United States.

In figuring weights of Steel Plates, add to above the allowances for overweight, adopted by Association American Steel Manufacturers, as shown on **page 14.**

NUMBER OF U. S. GALLONS IN RECTANGULAR TANKS.

For One Foot in Depth.

Width of Tank.	Length of Tank.																				
	ft. 2	ft. in. 2 6	ft. 3	ft. in. 3 6	ft. 4	ft. in. 4 6	ft. 5	ft. in. 5 6	ft. 6	ft. in. 6 6	ft. 7	ft. in. 7 6	ft. 8	ft. in. 8 6	ft. 9	ft. in. 9 6	ft. 10	ft. in. 10 6	ft. 11	ft. in. 11 6	ft. 12
2 ft.	29.92	37.40	44.88	52.36	59.84	67.32	74.81	82.29	89.77	97.25	104.73	112.21	119.69	127.17	134.65	142.13	149.61	157.09	164.57	172.05	179.53
2 6 in.	-----	46.75	56.10	65.45	74.80	84.16	93.51	102.86	112.21	121.56	130.91	140.26	149.61	158.96	168.31	177.66	187.01	196.36	205.71	215.06	224.41
3	-----	-----	67.32	78.54	89.77	100.99	112.21	123.43	134.65	145.87	157.09	168.31	179.53	190.75	202.97	213.19	224.41	235.63	246.86	258.07	269.30
3 6 in.	-----	-----	-----	91.64	104.73	117.82	130.91	144.00	157.09	170.18	183.27	196.36	209.45	222.54	235.63	248.73	261.82	274.90	288.00	301.09	314.18
4	-----	-----	-----	-----	119.69	134.65	149.61	164.57	179.53	194.49	209.45	224.41	239.37	254.34	269.30	284.26	299.22	314.18	329.14	344.10	359.06
4 6 in.	-----	-----	-----	-----	-----	151.48	168.31	185.14	201.97	218.80	235.63	252.47	269.30	286.13	302.96	319.79	336.62	353.45	370.28	387.11	403.94
5	-----	-----	-----	-----	-----	-----	187.01	205.71	224.41	243.11	261.82	280.52	299.22	317.92	336.62	355.32	374.03	392.72	411.43	430.13	448.83
5 6 in.	-----	-----	-----	-----	-----	-----	-----	226.28	246.86	267.43	288.00	308.57	329.14	349.71	370.28	390.85	411.43	432.00	452.57	473.14	493.71
6	-----	-----	-----	-----	-----	-----	-----	-----	269.30	291.74	314.18	336.62	359.06	381.50	403.94	426.39	448.83	471.27	493.71	516.15	538.59
6 6 in.	-----	-----	-----	-----	-----	-----	-----	-----	-----	316.05	340.36	364.67	388.98	413.30	437.60	461.92	486.23	510.54	534.85	559.16	583.47
7	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	366.54	392.72	418.91	445.09	471.27	497.45	523.64	549.81	575.99	602.18	628.36
7 6 in.	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	420.78	448.83	476.88	504.93	532.98	561.04	589.08	617.14	645.19	673.24
8	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	478.75	508.67	538.59	568.51	598.44	628.36	658.28	688.20	718.12
8 6 in.	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	540.46	572.25	604.05	635.84	667.63	699.42	731.21	763.00
9	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	605.92	639.58	673.25	706.90	740.56	774.23	807.89
9 6 in.	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	675.11	710.65	746.17	781.71	817.24	.77
10	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	748.05	785.45	822.86	860.26	897.66
10 6 in.	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	824.73	864.00	903.26	942.56
11	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	905.14	946.27	987.43
11 6 in.	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	989.29	1032.3
12	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1077.2

U. S. GALLONS IN ROUND TANKS.

For One Foot in Depth.

Dia. of Tanks	No. U. S. Gals.	Cubic Ft. and Area in Sq. Ft.	Dia. of Tanks	No. U. S. Gals.	Cubic Ft. and Area in Sq. Ft.	Dia. of Tanks	No. U. S. Gals.	Cubic Ft. and Area in Sq. Ft.
1 ft.	5.87	.785	5 ft. 8 in.	188.66	25.22	**19** ft.	2120.90	283.53
1 " 1 in.	6.89	.922	5 " 9 "	194.25	25.97	19 " 3 in.	2177.10	291.04
1 " 2 "	8.	1.069	5 " 10 "	199.92	26.73	19 " 6 "	2234.	298.65
1 " 3 "	9.18	1.227	5 " 11 "	205.67	27.49	19 " 9 "	2291.70	306.35
1 " 4 "	10.44	1.396	**6** "	211.51	28.27	**20** "	2350.10	314.16
1 " 5 "	11.79	1.576	6 " 3 "	229.50	30.68	20 " 3 "	2409.20	322.06
1 " 6 "	13.22	1.767	6 " 6 "	248.23	33.18	20 " 6 "	2469.10	330.06
1 " 7 "	14.73	1.969	6 " 9 "	267.69	35.78	20 " 9 "	2529.60	338.16
1 " 8 "	16.32	2.182	**7** "	287.88	38.48	**21** "	2591.	346.36
1 " 9 "	17.99	2.405	7 " 3 "	308.81	41.28	21 " 3 "	2653.	354.66
1 " 10 "	19.75	2.640	7 " 6 "	330.48	44.18	21 " 6 "	2715.80	363.05
1 " 11 "	21.58	2.885	7 " 9 "	352.88	47.17	21 " 9 "	2779.30	371.54
2 "	23.50	3.142	**8** "	376.01	50.27	**22** "	2843.60	380.13
2 " 1 "	25.50	3.409	8 " 3 "	399.88	53.46	22 " 3 "	2908.60	388.82
2 " 2 "	27.58	3.687	8 " 6 "	424.48	56.75	22 " 6 "	2974.30	397.61
2 " 3 "	29.74	3.976	8 " 9 "	449.82	60.13	22 " 9 "	3040.80	406.49
2 " 4 "	31.99	4.276	**9** "	475.89	63.62	**23** "	3108.	415.48
2 " 5 "	34.31	4.587	9 " 3 "	502.70	67.20	23 " 3 "	3175.90	424.56
2 " 6 "	36.72	4.909	9 " 6 "	530.24	70.88	23 " 6 "	3244.60	433.74
2 " 7 "	39.21	5.241	9 " 9 "	558.51	74.66	23 " 9 "	3314.	443.01
2 " 8 "	41.78	5.585	**10** "	587.52	78.54	**24** "	3384.10	452.39
2 " 9 "	44.43	5.940	10 " 3 "	617.26	82.52	24 " 3 "	3455.	461.86
2 " 10 "	47.16	6.305	10 " 6 "	640.74	86.59	24 " 6 "	3526.60	471.44
2 " 11 "	49.98	6.681	10 " 9 "	678.95	90.76	24 " 9 "	3598.90	481.11
3 "	52.88	7.069	**11** "	710.90	95.03	**25** "	3672.	490.87
3 " 1 "	55.86	7.467	11 " 3 "	743.58	99.40	25 " 3 "	3745.80	500.74
3 " 2 "	58.92	7.876	11 " 6 "	776.99	103.87	25 " 6 "	3820.30	510.71
3 " 3 "	62.06	8.296	11 " 9 "	811.14	108.43	25 " 9 "	3895.60	520.77
3 " 4 "	65.28	8.727	**12** "	846.03	113.10	**26** "	3971.60	530.93
3 " 5 "	68.58	9.168	12 " 3 "	881.65	117.86	26 " 3 "	4048.40	541.19
3 " 6 "	71.97	9.621	12 " 6 "	918.	122.72	26 " 6 "	4125.90	551.55
3 " 7 "	75.44	10.085	12 " 9 "	955.09	127.68	26 " 9 "	4204.10	562.
3 " 8 "	78.99	10.559	**13** "	992.91	132.73	**27** "	4283.	572.66
3 " 9 "	82.62	11.045	13 " 3 "	1031.50	137.89	27 " 3 "	4362.70	583.21
3 " 10 "	86.33	11.541	13 " 6 "	1070.80	143.14	27 " 6 "	4443.10	593.96
3 " 11 "	90.13	12.048	13 " 9 "	1110.80	148.49	27 " 9 "	4524.30	604.81
4 "	94.	12.566	**14** "	1151.50	153.94	**28** "	4606.20	615.75
4 " 1 "	97.96	13.095	14 " 3 "	1193.0	159.48	28 " 3 "	4688.80	626.80
4 " 2 "	102.	13.635	14 " 6 "	1235.30	165.13	28 " 6 "	4772.10	637.94
4 " 3 "	106.12	14.186	14 " 9 "	1278.20	170.87	28 " 9 "	4856.20	649.18
4 " 4 "	110.32	14.748	**15** "	1321.90	176.71	**29** "	4941.	660.52
4 " 5 "	114.61	15.321	15 " 3 "	1366.40	182.65	29 " 3 "	5026.60	671.96
4 " 6 "	118.97	15.90	15 " 6 "	1411.50	188.69	29 " 6 "	5112.90	683.49
4 " 7 "	123.42	16.50	15 " 9 "	1457.40	194.83	29 " 9 "	5199.90	695.13
4 " 8 "	127.95	17.10	**16** "	1504.10	201.06	**30** "	5287.70	706.86
4 " 9 "	132.56	17.72	16 " 3 "	1551.40	207.39	30 " 3 "	5376.20	718.69
4 " 10 "	137.25	18.35	16 " 6 "	1599.50	213.82	30 " 6 "	5465.40	730.62
4 " 11 "	142.02	18.99	16 " 9 "	1648.40	220.35	30 " 9 "	5555.40	742.64
5 "	146.88	19.63	**17** "	1697.90	226.98	**31** "	5646.10	754.77
5 " 1 "	151.82	20.29	17 " 3 "	1748.20	233.71	31 " 3 "	5737.50	766.99
5 " 2 "	156.83	20.97	17 " 6 "	1799.30	240.53	31 " 6 "	5829.70	779.31
5 " 3 "	161.93	21.65	17 " 9 "	1851.10	247.45	31 " 9 "	5922.60	791.73
5 " 4 "	167.12	22.34	**18** "	1903.60	254.47	**32** "	6016.20	804.25
5 " 5 "	172.38	23.04	18 " 3 "	1956.80	261.59	32 " 3 "	6110.60	816.86
5 " 6 "	177.72	23.76	18 " 6 "	2010.80	268.80	32 " 6 "	6205.70	829.58
5 " 7 "	183.15	24.48	18 " 9 "	2065.50	276.12	32 " 9 "	6301.50	842.39

31½ Gallons equals 1 Barrel.

To find the capacity of Tanks greater than the largest given in the table look in the table for a Tank of one-half of the given size and multiply its capacity by 4, or one of one-third its size and multiply its capacity by 9, etc.